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THE ENGINEER'S ENCYCLOPÆDIA.

THE

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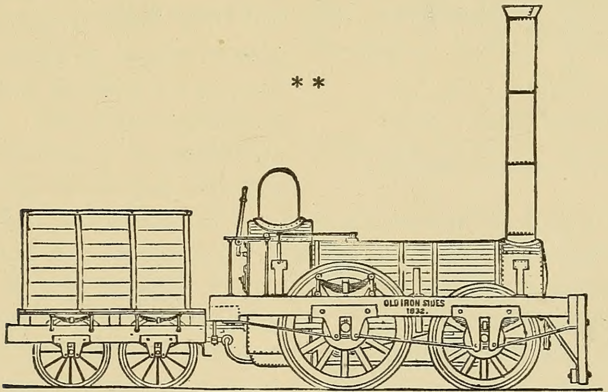
DESCRIPTIVE OF MACHINE TOOLS, HAMMERS, ELECTRIC ENGINEERING DYNAMOS, MAGNETS, MOTORS AND OTHER APPLIANCES OF ELECTRICITY, ETC.

BY

JOHN F. WINTON, Engineer, AND **W. J. MILLAR**, Civil Engineer,
Author of "Modern Workshop Practice." *Author of "Principles of Mechanics," etc.*

* *



THE "OLD IRONSIDES," 1832.

ILLUSTRATED BY OVER SIX HUNDRED ENGRAVINGS IN THE TEXT AND A SERIES OF SEPARATE PLATES.

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THE SCREW PROPELLER.

This mode of propulsion is now universally adopted in ocean-going vessels. For war vessels the screw propeller recommends itself because it and its machinery can be placed below the water line, and thus be protected in a great measure from the effect of shot; while for merchant vessels the advantages over the paddle-wheel arrangement consist in a saving in bulk and weight of the engines and boilers, by which the ship is enabled to carry more cargo, and greater coal stowage is allowed in cases of long voyages.

SHAFTING FOR THE SCREW PROPELLER.

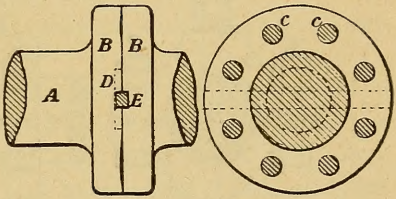

Fig. 349.—Coupling for Shafts.

A, Shaft. B B, Disc coupling. C C, Bolt holes. D, Projection recessed in. E, Key.

The arrangements in the passage from the engine to the after part of the ship, technically termed the "screw alley," first calls for notice. The line of shafting which connects the engine or cranked shaft with the propeller shaft is similar to any other line of shafting for general purposes. The most approved form of coupling is the solid disc forged along with each separate shaft, with a projection left on the one, which fits into a recessed hole turned out in the other. By this means the whole line of shafting is kept central the one with the other, and the discs are bolted together with bolts accurately turned and driven tightly into the holes, the holes being bored and rimelled out, and the discs faced for the heads and nuts to bear against. A key is fitted into the two discs, secured by screws into the one, but only fitting somewhat tightly into the other; by this means the shearing strain is taken off the bolts. Some engineers dispense with the key and projecting piece, having the ends turned quite fair, and depend on a greater sectional area of bolts for holding the discs together and taking the twisting strain. The part of each shaft which rests on the pillow block should be raised a little above the main part, and must be turned quite truly; at the same time in some cases it

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is advisable to turn the shaft from end to end with a rough cut, to insure a fair and true line, which tends to make the machinery run more smoothly; but when the shafting is truly forged this is not required.

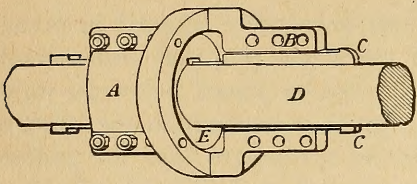


Fig. 350.—Repairing Coupling.
A, Coupling. B, Bolt holes. C C, Keys. D, Shaft. E, Recess for taking coupling on shaft.

Repairing couplings.—The lying shafting is generally fitted rough from the steam hammer. In the event of one of these shafts breaking, a ready means for temporarily repairing it is of the highest importance. In the example (Fig. 350), the coupling is made in four pieces, bolted together lengthways with flanges, and transversely with bolts passing through discs cast on the coupling, the torsional strain being taken on four keys.

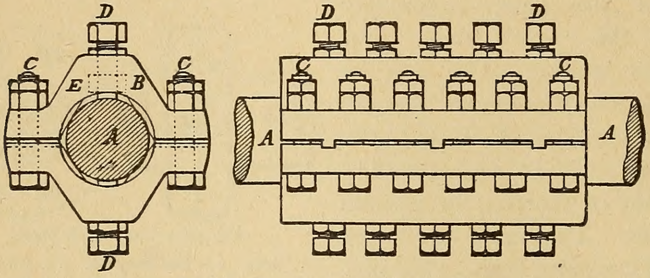
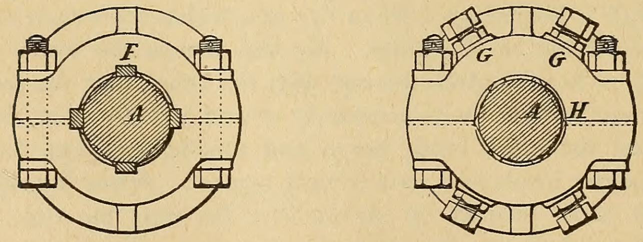


Fig. 351.—Repairing Coupling in Cast Steel or Wrought Iron.



Figs. 352, 353.—Repairing Couplings in Cast Iron.
A, Screw shaft. B. Coupling. C C, Bolts. D, Set screws. E, Recessed nut. F, Keys. G G, Set screws. H, Raised strips.

We have arranged a simpler form of coupling, which possesses the following advantages. It is evident that a shaft breaking at sea must be repaired as speedily as possible, and that the contact between the rough shaft and the coupling must only be partial, otherwise it would be impossible for the best mechanic to adjust the one to the other in a limited time. The points of contact are taken on raised strips, cast or forged on as the case may be, forming a V section, with flat parts cut across the shaft, and the fracture is drawn together by means of the longitudinal flanges and bolts. There are four series of strips in the length of the coupling, making sixteen points of contact in all. These couplings can be fitted with keys for taking the shearing strain; but it is evident that cutting and filing up key beds on the shaft in a heavy seaway would be a work of difficulty, and therefore in emergencies the necessary amount of grip can be obtained with a series of cupped set screws and nuts recessed in the coupling, considering that the coupling of the V section takes the greater part of the torsional strain. To lighten these couplings so that they can be easily adjusted, we propose making them of cast steel. Wrought iron or even cast iron can be used, but the latter will be of considerable weight; and perhaps the more expensive material may not be considered too much, when we remember that the light coupling is more easily handled on board ship.

The *pillow blocks* are of cast iron, lined with white metal; they are quite plain, and are fitted with a cover, parting at the centre line. Oil cups are cast on the top of the covers, fitted with pipes, syphon wicks, and light cover. The base of the block is quite flat, and is generally bolted down to wooden beams placed on the top of wrought-iron standards, which are carried up from and strongly rivetted to the floor plates. The pillow block for receiving the thrust or forward motion of the line of shafting imparted by the action of the screw propeller—this push being always in the direction of the path of the vessel, whether moving ahead or astern—

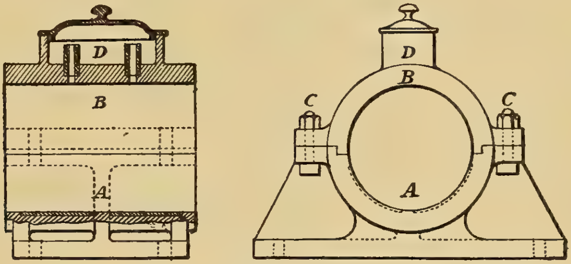


Fig. 354.—Pillow Block for Shafting.

A, Pillow Block. B, Cover for do. C C, Bolts and nuts. D, Oil cup.

must be fitted with a series of collars in the bushes for taking a corresponding series turned on one of the lying shafts, generally located near the engine end, although they are sometimes fitted at both ends of the shafting. These bushes are fitted into the pillow blocks in the usual manner, and are secured with a cover and bolts, with oil cup cast on, and pieces left to form the pipes for the syphon wicks, having holes bored through the top brasses for each collar on the shaft. The block is cast with a long bottom piece, which is bolted down to a separate plate planed for its reception, and fitted with joggles for firmly wedging the block and plate together, the latter being securely joggled and bolted to the wrought-iron stan-

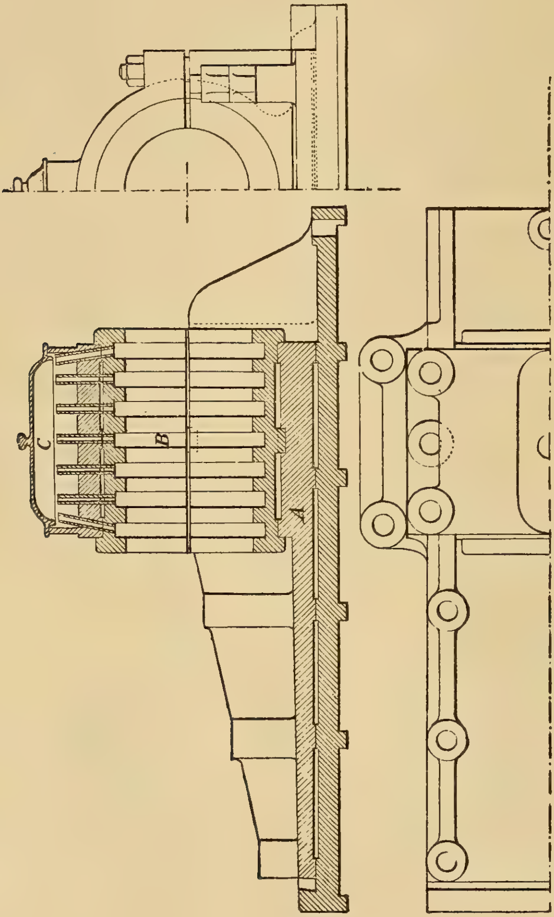


Fig. 355.—Thrust Block.

A, Thrust block. B, Cover for thrust block. C, Oil cup.

dard frames rivetted to the top of the floor plates. In connection with the pillow blocks, a water pipe is carried along the entire length of the screw alley, supplied from the same source as for the main bearings of the engine, and fitted with a plug tap for each bearing, with flexible pipe and water distributor for showering the water by hand all over the bearing in the event of heating.

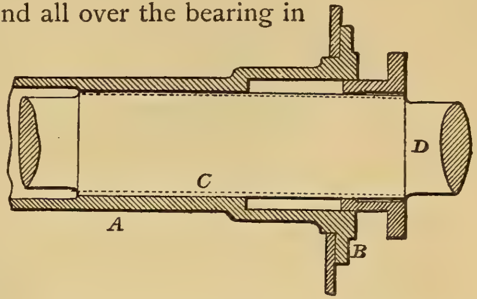


Fig. 356.—Stern Tube, forward end.
A, Stern tube. B, Flange. C, Stuffing box and gland. D, Shaft.

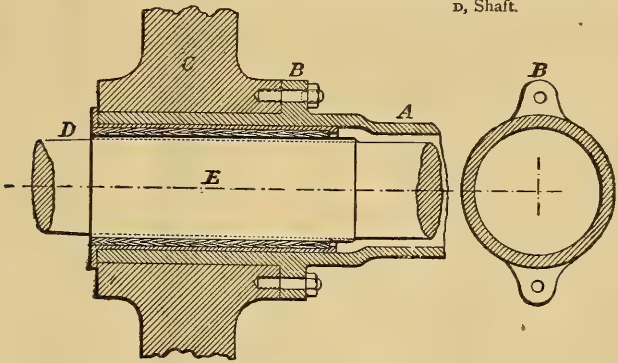
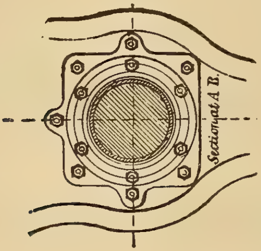
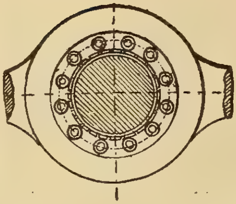


Fig. 357.—Stern Tube, aft end.
A, Stern tube. B, Snugs. C, Stern post. D, Tube with lignum vitæ. E, Brass bush on shaft.

The *stern tube* is made of cast iron, and of sufficient length to suit the fineness of the run of the vessel. A flange is cast on for bolting it to the plate laid across the ship from frame to frame, by which the tube is firmly pressed into the tapered part of the stern post, a corresponding taper being accurately turned on its own end. A packing space is left, fitted with a gland cast in brass or of cast iron lined with brass, for packing the shaft and rendering it perfectly water tight; care must be taken that ample room is left between the gland and the skin of the ship. The tube has rings cast on and turned; these rings are placed to suit the frames of the ship, which have plates accurately bored out, and in this way the tube is supported along its entire length. At the extreme end of the tube a brass bearing is let in, having strips of lignum vitæ for the bearing surface. This was found an immense improvement over the ordinary brass bushes, and has been a chief cause of the great success of the screw mode of propulsion. Without this wooden bearing surface solely lubricated by the sea water, it would be impossible for ships to remain long on any station without incurring constant expense in docking them to repair the bushes, as was required in the old method, where the action of the screw soon played sad havoc with the brass bushes, wearing them by repeated blows out of truth, and consequently shaking the after part of the ship.



End View at Stern Post.



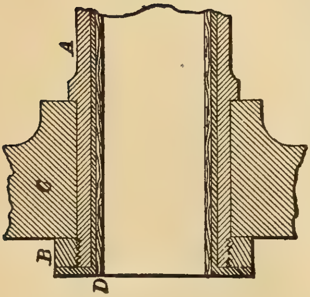


Fig. 353.—Method of securing the Stern Tube, &c.
A, Stern tube. B, Nut. C, Stern post.
D, Tube with lignum vitæ.

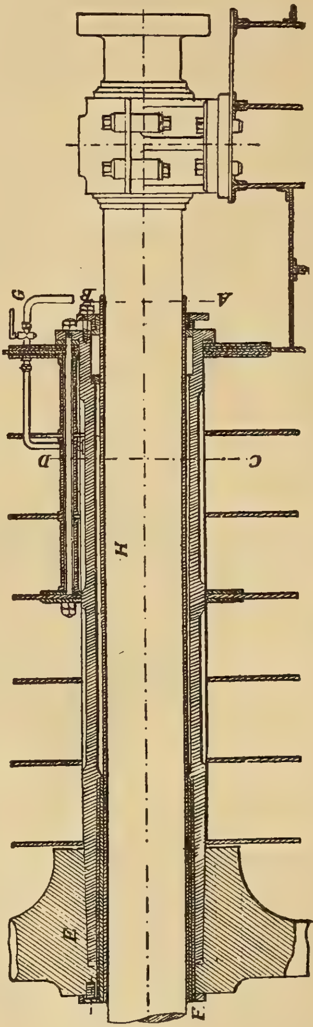


Fig. 359.—Stern Tube, &c. — A B, Across the shaft at the stuffing box. C D, Across the shaft at the securing bolts.
E, Stern post. F, Tube with lignum vitæ. G, Water pipe. H, Shaft with covering tube of brass.

Figs. 357 and 358 show methods of securing the stern tube to the stern post. In some examples where the stern tube is turned tapered at the end, fitting into a corresponding hole bored out in the stern post, as will be seen by Fig. 359, the tube is held in position by three large bolts, with distance pieces of cast iron placed between the floor plates of the ship, which are strengthened with extra plates at the front end and at the middle of the tube, and bored out for the reception of the raised parts on the tube, also truly turned. The tube is fitted with the usual brass bush, lined with lignum vitæ, and is bolted by a flange and stud bolts to the stern post. The fore end has a cast-iron gland bushed with brass, with a brass bush at the bottom of the stuffing box, which prevents the water entering the ship.

The screw shaft should be made of larger diameter than the lying shafting, and is fitted with a disc for connecting it to the latter, and also with a thrust block, by which the longitudinal pressure from the action of the screw is partly taken, relieving in a measure the forward one. Raised parts are left on the shaft at both ends, for shrinking on brass tubes for the end bearing, which should be of great length. At the end of the shaft a tapered part is turned, with a collar near the front extremity, and screwed with a bold square thread at the extreme end, which is fitted with a nut and washer for pressing the screw propeller up against the collar. Sometimes the end of the tube is fitted with a packing ring, to prevent the water acting on the end where it is let into the stern tube.

In the navy and also in some mercantile vessels hollow propeller steel shafts are used. The outside diameter is usually about double of the inside diameter, and the steel is that known as Whitworth's fluid compressed steel, *i.e.* the casting is made with a core, and compressed by hydraulic pressure of from 5 to 6 tons per sq. inch, and thereafter drawn out by hammering to the required length.

CONSTRUCTION AND FORMS OF THE PROPELLER.

Before discussing the action of the screw propeller, we will consider its form and construction. The boss or centre piece, as in an ordinary screwed bolt, may be said to form the bottom of the thread, and the blade forms the thread itself. The thread of a screw can be illustrated by rolling a piece of paper cut in the form of a right-angled triangle round a cylindrical piece of wood: the base is the circumference, the perpendicular is the pitch, and the hypothenuse is the line that will delineate the thread when wound round the wood. Thus a point on the thread, when working in a nut with a corresponding thread, will move forward the extent of the pitch in a single revolution. In this way the screw propeller may be termed an endless screw, working into an endless nut—the ocean. Thus supposing the pitch of the screw is 20 feet, and the distance the vessel has to go forward 4000 feet, the screw propeller would require to make 200 revolutions to move the vessel that distance. The action of a cork-screw is similar to the action of the screw propeller: with each revolution of the screw a certain progressive movement is made through the cork, due of course to the pitch or spiral of the screw; but as the screw propeller moves in a yielding fluid, sometimes the action ceases by the thread of the watery nut becoming as it were broken for a time, and the propeller revolves without imparting any forward motion to the vessel. This is termed the "slip" of the screw, and varies from about 10 to 20 per cent. Again we have what is termed "negative slip," the screw moving through less space (even although working as in a solid nut) than the speed of the vessel, the vessel as it were outstripping the screw and dragging it through the water. This negative slip occurs only in vessels having full after lines; in those having a clean run aft it is never felt. The question of the best pitch for the screw propeller depends on the lines to be given to the ship, and shows the necessity for the builder and the engineer working hand in hand. When a maker of marine engines contracts for the machinery of a vessel built by another firm, he should always be provided with the full lines of the ship, so as to meet the requirements of the particular case. Some screw propellers are made to feather, by which means the best pitch for propelling the vessel cheaply is arrived at; but it is not advisable to carry this practice too far, for then the blade of the screw presents neither more nor less than the action of an oblique board. And although we may be able to get a little more speed out of the vessel by this deviation from a truly scientifically constructed propeller to suit the known run of the vessel as found, surely it is preferable to arrive in the first instance at the pitch to be adopted, which can only be successfully found by studying the lines of the ship, and comparing them with former practice. And when we do get a good result from the best form of vessel yet constructed, it can be used as the basis for further improvements, increasing the speed of the ship if desired, bearing in mind that the power required varies as the cube of the speed. The question of relation between power and speed has received recently much attention through progressive speed trials carried out by Mr. William Denny of Dumbarton, who, as to the usual formulæ or rules, says:—"The common fault is the supposition that the power required to produce certain speeds varies as the cubes of these speeds. This is a very fallacious theory, and one which experience does not bear out." See page 513 for an investigation of this question.

In the moulding shop a nearly uniform plan of constructing the moulds is adopted for all the forms of screw propeller. In the early screws the boss was round, tapering from the front to the back to suit the taper turned on the screw shaft, the thickness of the boss being greater at the front, with a reduced thickness at the end of the shaft. The blades are formed or struck up by means of a board, revolving round a central spindle, placed vertically in the centre of the mould for the boss. An inclined plane is formed of wrought-iron plating to suit the pitch required, and this plate is bent round to the true circumference of the outer diameter of the blades; in this way the mould is formed of loam by moving round the board on the edge of the wrought-iron plating, care being taken that the board always moves upwards on the spindle in a level manner; the bottom edge of the board then scrapes the loam, which is built up on a large cast-iron plate, and the true flat form of the screw's disc is described. It is then necessary to divide the outer circumference of the blades, which is generally one-sixth of the total circumference, or the radius of the blade from the centre to the point, the sides or edges of the blade radiating from those points on the circumference to the centre. The thickness of the blades at the point and root is then laid on, the corners of the blade at the circumferential line are rounded off, and the mould finally finished for casting. With this form of screw propeller, a great portion of the central part of the blades strikes the water nearly flat, merely disturbing the water, and throwing it off at right angles to the path of the vessel, causing much vibration without producing any useful effect. It was also found that the greatest effect was produced by cutting down the blades at the circumferential line, and forming the edges curved, having the greatest breadth nearer the centre, instead of on the extreme circumferential line of configuration.

This effect of vibration in the earlier screws was got rid of in a measure by making the boss spherical, and filling up a great portion of the central part of the blades with the ball, from which the water glides off, while the blades cut their passage through the water in a more direct line, instead of striking it at right angles to the vessel's path. This is the greatest improvement that has as yet been introduced in the formation of the screw propeller, and it is now universally adopted, in some cases with slight but non-essential variations.

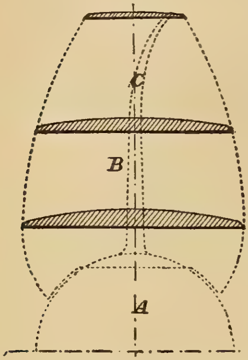


Fig. 360.—Form of Blade very generally adopted.

A, Boss. B, Blade. C, Blade showing thickness of metal.

Great difference of opinion exists as regards the number and configuration of the blades for the screw propeller. When the vessel is pitching or rather plunging in a heavy sea, a two-bladed screw cannot have so much hold of the water as one with three or more blades; but the two-bladed screw possesses a great advantage in being more easily lifted for repair or inspection; and in addition the "well," as it is termed, that is cut down from the deck does not require to be so large. For war vessels so fitted, two-bladed screws are adopted; but for the mercantile marine three and even six blades are beneficially used.

The common propeller is arranged for two, three, or four blades; they are generally cast along with the boss, of an elongated or spherical shape. The side view of the blade is quite parallel and more or less rounded at the point, and the thickness gradually tapers from the centre to the point. Some of the common forms

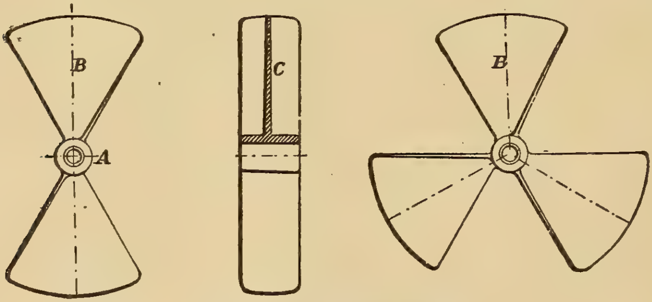


Fig. 361.—Common Screw Propeller.

A, Boss. B, Blade. C, Blade showing thickness of metal.

are made to feather, and are arranged for four blades, having a flange on each blade, which is turned, fitting into recesses cast and turned out in the boss, the end of the blade having a projection cast on, and turned to fit holes in the boss bored out exactly. The blades are bolted to the boss with a number of bolts all round the flange, fitted with elongated holes in the blades. The hole for receiving the propeller shaft is turned of a tapered form, and the propeller is screwed hard into its place with a large nut at the end, having a recessed key on the shaft to prevent the propeller turning round. Some engineers have fitted keys through the boss for this purpose, but these are not required, as practice has proved that with a proper taper on the shaft the nut is powerful enough to hold the screw firmly in position, the grip being quite sufficient to resist the torsional stress imparted from the blades turning round in the water.

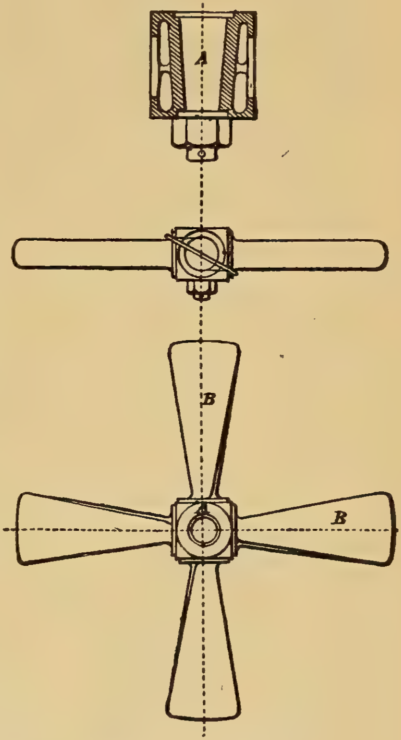


Fig. 362.—Feathering Propeller with four Blades.
A, Boss. B, Blade.

In some arrangements for twin-screw propulsion, two propellers have been fitted to each shaft, one before and another behind the hanging outside bearings, by which plan more propelling surface is obtained for vessels of light draught. The forward screw having a finer pitch than the after one, the water given off or pushed back by the one is taken up by the other. This plan is correct in theory, whether applied to the screw or paddle wheel. It is more evident in the latter case, where the tail water given off by the forward paddle wheel acquires a certain velocity; and when two wheels have been fitted to each side, the after one must have a larger diameter, or be driven at greater velocity, so as to pick up the tail water beneficially. To carry out this principle more fully in the screw propeller, two blades have been cast on the same boss, one in advance of the other, or, in other words, a two-bladed screw is formed in duplicate. It is advisable to cut away the sides from the middle of the blades to the centre (as seen in Fig. 363), by which means the water is not churned so much, while the after blade gets a better grip. In other forms six blades have been successfully adopted. The blades are narrow and almost parallel in the front

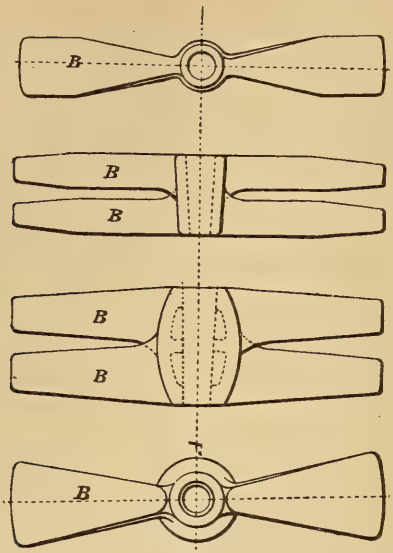


Fig. 363.—Two Propellers cast on one Boss.
A, Boss. B, Double blades.

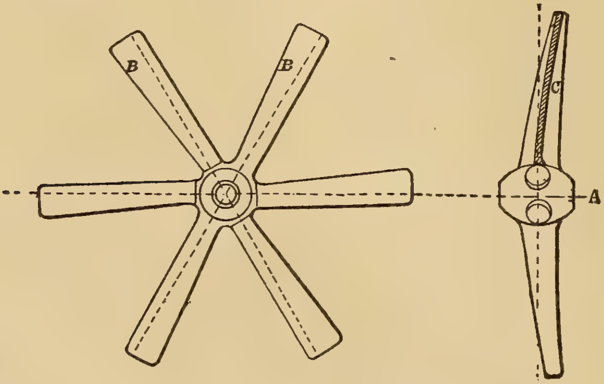


Fig. 364.—Six-bladed Feathering Propeller.
A, Boss. B, Blade. C, Blade showing thickness of metal.

view; in the end view they are bent backwards. This form presents a number of blades of small area, and it gives equal satisfaction in other arrangements with two or more blades of greater surface in each; but it is obvious that it is not nearly so strong as the ordinary mode of construction, and therefore more liable to get damaged.

We now notice a form of propeller which has been extensively used both in the royal navy and the mercantile marine. The boss is of a ball shape, and may be considered damage proof; the blades have a curved shape on the sides, and their greatest breadth is at the centre or nearly so; the points and that portion cast on the boss are made narrow; they are bent forward at the points, by which a better grip of the water is obtained. This form of propeller has generally either three or four blades, all cast along with the boss. The success which has attended it has produced various

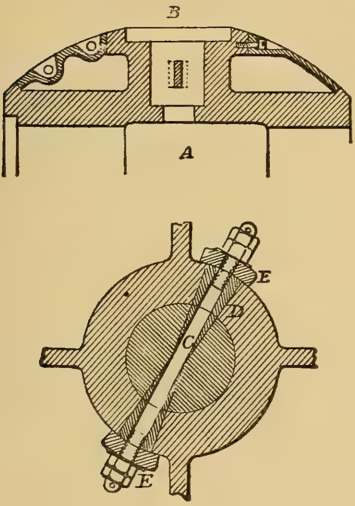


Fig. 365.—Boss for a Six-bladed Feathering Propeller.

A, Boss. B, Blade. C, Key. D, Wedge pieces. E E, Plates.

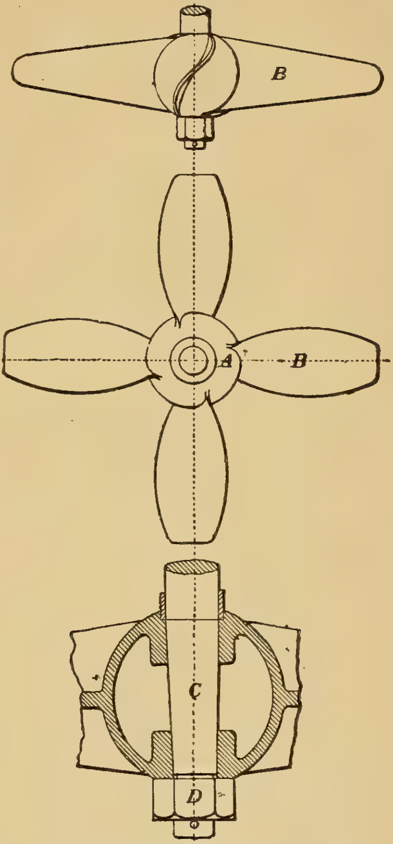


Fig. 366.—Four-bladed Propeller cast on the Boss.

A, Boss. B, Blade. C, Taper on shaft. D, Nut with split pin.

modifications in the form of the blade, by which its general appearance has been altered, but its usefulness in no way improved. With the view of arriving at the best pitch for propelling the vessel, the designer of this form generally prefers the blades cast separate from the boss, and all keyed to it by a key passing through a shank accurately turned to fit a corresponding hole in the boss; the flange has also elongated holes all round through which bolts pass; by this means a greater or less pitch is given to the blades, the number of which is generally two, although three can also be conveniently adopted. All these screws are either fitted with a large nut for firmly screwing or forcing them in the tapered part left on the propeller shaft; or are held in position by flat side keys, a part being cut in the shaft for their reception. The keys are driven tightly in, bearing laterally and longitudinally against the boss and the shaft, and are held in position by a nut and lock nut bearing

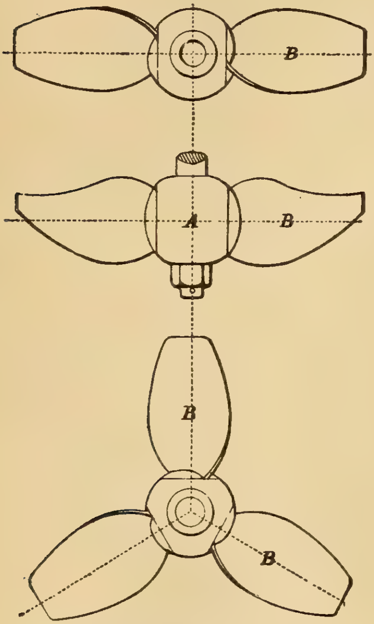


Fig. 367.—Feathering Propellers.
A, Boss. B, Blades.

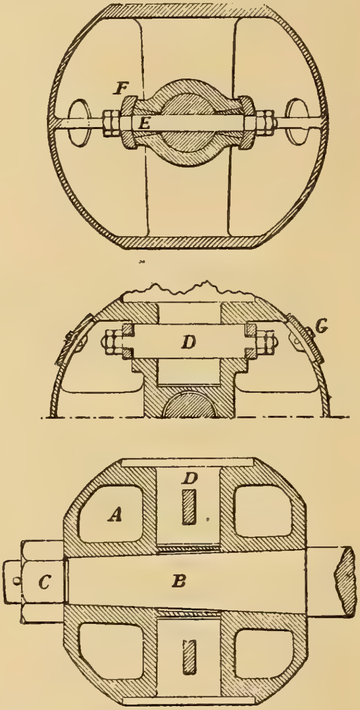


Fig. 368.—Boss for Feathering Propeller.
A, Boss. B, Taper on shaft. C, Nut and split pin. D, Key. E, Wedge pieces. F, Plate. G, Plate fitted to hole for putting in the key.

on a suitable washer, the whole being inclosed within the hollow boss properly strengthened in the casting.

The mode of attaching the blades to the boss is by a cotter passing through the shank and boss, and held in position by nuts and lock nuts at each end, bearing on washers, the hole being cut of a wedge form, tapering to the centre of the cotter. By this means the blade can be turned in either direction for feathering, or for adjusting the pitch; and when the pitch is once fairly adjusted, the blade can then be firmly held in the proper position by driving in wedge pieces between the boss and the cotter, the washers and nuts preventing them shaking loose.

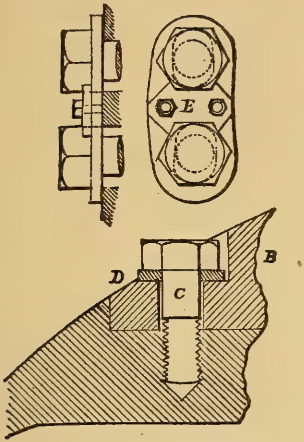


Fig. 369.—Bolt Fastenings.
A, Boss. B, Blade. C, Bolt. D, Plate.
E, Guard plate.

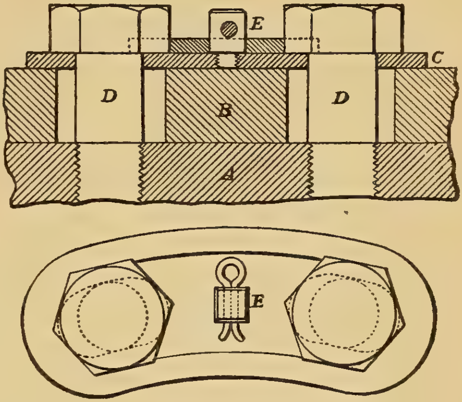


Fig. 370.—Bolt Fastenings.
A, Boss. B, Blade. C, Plate. D D, Bolts.
E, Guard plate.

The bolts for the flanges of the blade when so fitted are generally tapped into the boss, the head bearing on a plate fitted to two of them. Various plans are adopted for preventing these bolts from turning round: by notching the head for a split pin, or by notched washer plates fitting to the heads and secured with set screws, or with stud and split pin tapped into the bottom plate, or by small square pieces butting against the nut, held with a single set screw, the bottom washer or plate being

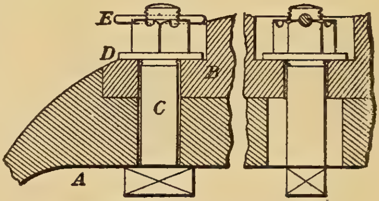


Fig. 371.—Bolt Fastenings.
A, Boss. B, Blade. C, Bolt. D, Washer.
E, Split pin.

bored with a number of holes, so that the plate can be shifted to accommodate the head. Others use T bolts, which are let into the boss, the nut being cross cut at the top for a split pin to pass through, which prevents it from turning round; a plan likewise adopted when the bolts are tapped into the boss.

Propeller blades are made of cast iron or steel, and recently bronze has been used for this purpose. The advantage in using bronze for propellers lies in the greater durability and the smoothness of the skin. Manganese bronze has now been in use

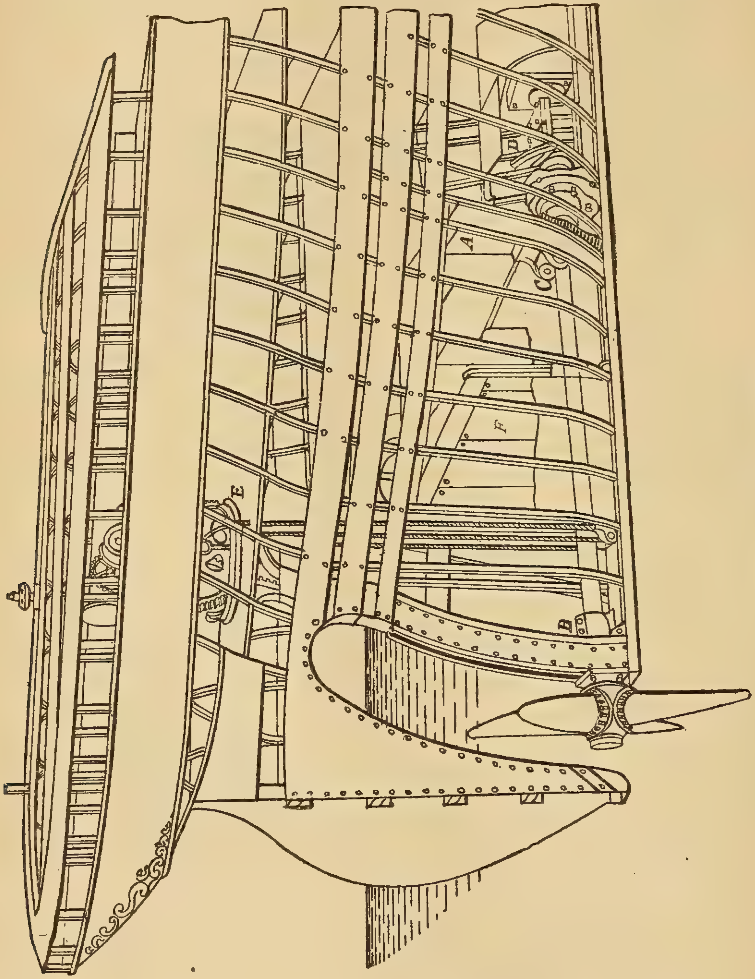


Fig. 372.—Lowering Propeller.

A, Bulkhead. B, Sliding bush. C, Radial gland. D, Pillow block. E, Lifting gear. F, Well.

by the Admiralty and mercantile firms with good results. The blades can be made thinner and smoother than with steel, the latter suffering from corrosion. The cost of the former is greater than steel, but the endurance being in excess economy appears to be attained by its use.

Plan for Lowering the Propeller below the Keel of the Ship.—In long ships the pitching in a heavy sea, and the vertical motion of the waves, injuriously affect the action of the propeller when fitted in the usual way, causing the engines to "race" dangerously, as well as diminishing the speed of the vessel. In Fig. 372, the propeller is shown in its normal position, the shaft being in a straight line with the rest of the shafting. On the ship arriving in shallow water the screw is raised so that the point of the blades rotate above the level of the keel; and the shaft can be still further raised, exposing the boss, when the ship is in light trim. In this way a broken blade can also be replaced without dry dock accommodation.

To effect this movement of the screw the two last lengths of the shafting are coupled with a universal joint, the inboard shaft having a fixed pillow block, while the screw shaft is fitted with a sliding bush, lined with strips of lignum vitæ in the usual manner. The bush is guided by the two cheeks of the stern post, and it is raised by means of a rack which passes upwards and is connected by gearing to a steam engine placed on the upper deck. The shaft works through a slot in the after bulkhead, the water being excluded by a radial gland working on two centres; while the universal joint works in a chamber in the after end of the screw alley, and is at all times accessible to the engineers. The lifting rod and gearing are inclosed in iron casings, which extend to the upper deck, and exclude any water that may rise. To prevent warps from fouling the screw when raised in shallow water, a sliding keel is run out by a mechanism placed on the upper deck. The want of the usual keel piece joining the inner and outer stern post is fully compensated by the increased width and extra thickness at the head of the screw aperture, the centre of effort of the rudder being raised above the ordinary height. A false foot is fitted to the bottom of the rudder post, which can be readily removed, allowing the screw boss to be changed in a dry dock without disturbing the shaft.

RAISING THE SCREW PROPELLER AND SHAFT.

The first point to be considered in our plan for raising the shaft and screw at an angle from a point forward from the stern post, is the swivelling action fitted to a water-tight bulkhead, with all the usual appliances now in use for securing an efficient bearing for the shaft. On consideration we think that the hemp-packed ball-and-socket joint is best adapted for this purpose. A perfectly water-tight joint with great swivelling action can be attained by clasping the short swivelling tube with an elastic ring expanded over the tube, at the same time compressing the ring into a recessed gland, in a way similar to what we adopted some years ago for packing the tubes of the surface condenser; but as part of the weight of the propeller is taken at this swivelling centre, the plan is not rigid enough, and a hemp-packed metallic ball and socket is to be preferred. This should be fitted with a lignum-vitæ bearing, and stuffing box for the shaft; the socket having a projecting ring cast on, which is accurately turned, and fits into a strong ring rivetted to the bulkhead, the ring projecting through a hole cut in the bulkhead, which is made very stiff at that part; this ring is bored out in the ship in the usual manner. The seating has likewise a flange cast on for bolting it firmly to the ring. The gland for the stuffing box of the ball is made very strong, for taking the inward

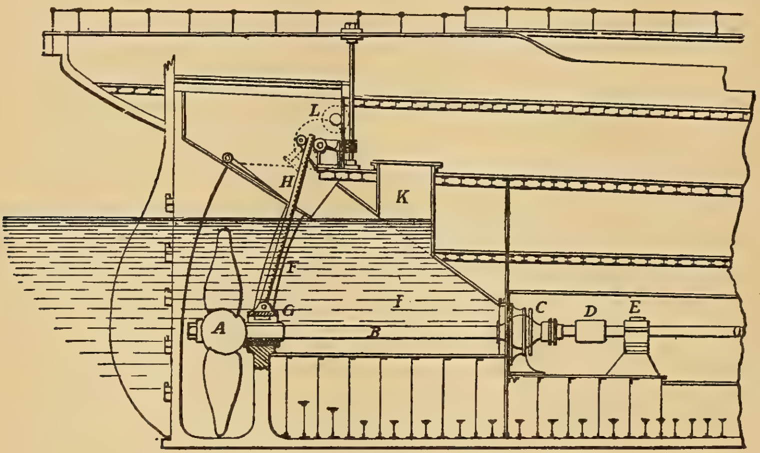


Fig. 373.—Lifting Gear for Screw Propeller.

A, Propeller. B, Shaft. C, Ball and socket. D, Coupling. E, Pillow block. F, Curved stern post. G, Bearing. H, Rack. I, Well. K, Manhole. L, Steam purchase.

pressure due to the head of water, as well as for clasping the ball firmly, preventing it from turning; while the hemp packing has but little to do, as there is no movement of the ball when the shaft is revolving. When the surfaces of the ball and socket are properly machined in the workshop, the same means being used for turning the ball-and-socket connections as for the locomotive engine, the two surfaces will be mathematically exact and perfectly water-tight.

The stuffing box for the shaft is of the usual description, fitted with a lantern brass for keeping the shaft properly lubricated with oil. On the under side of this stuffing box a broad flat sector is fitted, the principal use of which is for holding the ball at any angle, and which may be made stiff enough to prevent any movement of the ball.

The coupling may be of the disc description, having a concave surface on the one side and convex on the other, or as it were part of a ball and socket; this form we consider necessary to raise the shaft easily at an angle. Part of the surfaces remain in contact when the shaft and propeller are raised for inspection or to replace a broken blade, or when the vessel is under wind power alone. But as we consider the propeller shaft should be placed in from the stern of the vessel, so as to be able to replace a shaft at sea or when lying in harbour, we propose using a box coupling for the connection between the propeller shaft and the main line of shafting.

The outside bearing brass for the shaft is cast in two halves, the division being in a vertical line, and is fitted with lignum vitæ in the usual way. Flanges are cast on the brass at the under side, and secured with bolts and nuts. The top is secured by a cap of brass or wrought iron; if the latter is used it should be dipped in a zinc bath to prevent oxidation. The flanges cast on the brasses for taking the cap are quite flat across the bearing; all the bolts should be of Muntz metal, with brass nuts. There is a bottom bush of metal, which is accurately turned, and fits into the half eye formed on the stern post; this bush is bored out conically, for taking a corresponding turned part on the brass bush. The stern post is bored out in the ship along with the ring fitted to the water-tight bulkhead. The cap has two lugs forged or cast on, for taking an eye formed on the lifting rack; the eye should be bushed, and the pin forming the joint made of Muntz metal. The cap has a part cut out at the sides which work in the sector guides, placed on each side of the well formed in the stern of the vessel, the curve of the guiding plates being struck from the swivelling centre.

The hoisting gear for small propellers is placed on the deck, and consists of a screw and worm wheel, with a pinion on the worm-wheel shaft, working into teeth cut in the rack, which is directly connected by the pin joint on the bearing cap; the rack slides on a roller placed at the top, opposite the pinion on the worm-wheel shaft. This gear is sufficient for small propellers, and has the advantage of sustaining the weight in any position without the use of pauls, as in ordinary crane purchases. Of course, steam power may be used, as shown in Fig. 373; and the arrangement can be modified for propellers of the largest size.

The inside stern post is carried up just a little above the centre line of the shafting; the curved guide plates may either be rivetted or forged on. These guide plates are also rivetted to the side of the well, which is carried forward to the bulkhead, and strongly rivetted to the angle-iron ring, as shown. The stern post and the keel are stiffened with a plate, rabbetted to the keel and to the stern post, and firmly rivetted to it, and to the under side of the well and the bulkhead, by means of angle iron. Every alternate floor plate is also carried up and rivetted to the plating forming the well, which is carried up to the under side of the deck, forming a very strong attachment between the keel and the top of the ship. A manhole is fitted to the top of the well inside of the ship, through which a sling can be attached to the under side of the shaft, when lifting it out or putting it in; another sling passes over the boss of the propeller at the top end. Before lifting the shaft out, a guiding shackle is hung from and secured to the manhole.

We will now describe the manner in which by this arrangement the shaft and screw are lifted and again replaced, when the vessel is at sea or lying in some foreign port. In the first place the box coupling on the end of the shaft and inside of the ship must be drawn back; the gland bolts on the socket holding the ball slackened a very little, and the nuts on the sector underneath eased: then we are ready to lift the propeller and shaft. Before doing so the manhole cover should be removed on the top of the well, and all the necessary tackle be got in readiness. The propeller and shaft are then raised a little with the hoisting gear, and the blades of the screw taken off the boss; the shaft is then lifted a little farther, to the angle of inclination for withdrawing it out of the ball and socket; prior to which a blind flange with a short pipe accurately bored and turned is slipped over the end of the shaft, with a ring of india rubber placed over the short tube. The slings are then put on the shaft, and when the top one can be attached to a crane, it is easily drawn out of the ball, the blind flange and short pipe follows it up, and takes the place of the shaft, keeping the packing in its proper position; the flange is then screwed up with the same nuts as for the gland, and in this way a double protection is afforded by the ring joint against water getting into the ship. The guiding shackle is then fastened to the manhole, and as it is only a foot or so below the water, it acts as a guide in placing the shaft in again. When the shaft is clear of the ball it can be easily lifted out; and it is replaced in the same way; the ball being held at the inclination by the nuts on the sector placed underneath the socket. When the shaft is put in again, it is passed through the top bearing brass, then through the guiding shackle, and is lowered into the wooden bearing in the ball, and then into the short pipe on the blind flange. A small testing tap is fitted on the flange, for allowing the compressed water to escape, as also to prove if the packing around the shaft is perfectly tight before withdrawing or taking off the flange or pipe piece.

THE COMPOUND ENGINE.

The Cornish engineers have for a long period taken the lead in the important matter of the economy of the steam engine, some of their large pumping engines doing duty with barely 3 lbs. of coal per actual horse power per hour. This result is due to the high steam pressure used, cutting off the steam soon, and working with a large measure of expansion, for which the long stroke of the piston in these engines is admirably suited; these facts, combined with the careful clothing of the parts where radiation takes place, account for the small amount of fuel consumed over that of ordinary engines. The principle of compounding was tried many years ago by Hornblower, Woolfe, and M'Naught, but was not introduced successfully into marine practice till 1854, when Messrs. Randolph, Elder, & Co. fitted up the steamer *Brandon*. The first vessel of

H.M. navy to be fitted with compound engines was the *Constance*, built by the same firm in 1863. In marine engines the Cornish principle has to a certain extent been carried out. Large cylinders have been adopted, but we consider that there is still great room for improvement. Longer strokes should be aimed at, although there must be a limit in this direction, owing to the confined space of the midship section of steam vessels; but with horizontal engines on the return connecting-rod principle there is nothing to hinder the introduction of strokes of 4 feet 6 inches and upwards for engines placed in exceedingly fine sections. This for medium power would be a great advantage over those engines having a stroke of 3 feet or so. A full measure of expansion with a single cylinder has often been obtained, and with good results; but there are certain difficulties to contend with, the chief one lying in the details, as all the parts require to be made of extra strength, and when 60-lb. steam per square inch is used, with a large area of piston, the engine becomes very heavy. This is not at all to be desired, as the permanent load should be kept as low as possible, more especially for high-speed horizontal engines, there being no doubt that the wear and tear of large heavy pistons and their adjuncts forms a serious item of expense on board ship. Trunk engines have been recommended, so as to carry up as it were the weight of the piston; and there is little doubt that the large surface of the trunks tends to lessen the wear, but it does so at the expense of lubricants, more especially with the high pressure and dry steam now adopted.

To obviate the defects inherent in the single-cylinder arrangement, using high steam with a large measure of expansion acting on these great pistons, the Compound Engine has been adopted to a considerable extent; although the same type of engine is by no means a novelty, as, for manufacturing purposes requiring great regularity of motion, beam engines fitted with high and low pressure cylinders have long been used. The motion is very easy and uniform, more especially at the beginning and ending of the stroke of the piston, which is due to the steam expanding from the bottom of the small piston to the top of the large one, and *vice versa;* thus the steam from the boiler acting on the small piston is met by a counteracting pressure, which tends to lessen the shock more or less felt with ordinary engines. The large or low-pressure cylinder is placed at the end of the beam, and the small or high-pressure cylinder is usually one-half of the diameter of the low-pressure one;

the contents of the smaller cylinder is about one-fifth of that of the large one, owing to the stroke of the high-pressure piston being shorter, consequently when the steam is admitted the entire length of the stroke it afterwards expands into the large cylinder, the measure of expansion, theoretically speaking, being as five to one. Practice and theory are fully carried out in this arangement; the steam, after doing duty in the high-pressure cylinder, is immediately taken up and expanded in the low-pressure one, and then exhausted into the condenser. Some of those engines have a fixed measure of expansion, the valves having no lap, thus admitting the steam from the boiler into the cylinder the entire length of the stroke of the piston; in others the expansion of the steam is more fully carried out by cutting it off in the high-pressure cylinder. In marine engines this principle is carried to the utmost limit by cutting off quickly in the high-pressure cylinder; thus in the first instance there is a large measure of expansion taking place in the small cylinder before the steam is admitted into the large one, where it is still further expanded.

The late Professor Rankine, in treating of this subject, defines a compound steam engine as "one in which the mechanical action of the steam commences in a small cylinder and is completed in a larger cylinder;" these engines, again, are divided into two classes: "first, those in which the steam passes directly, or almost directly, from the high-pressure to the low-pressure cylinder," the forward stroke of the latter cylinder taking place either exactly or nearly at the same time with the return stroke of the former cylinder; and secondly, those in which the steam, on its way from the high-pressure to the low-pressure cylinder, is stored in a reservoir, so that any convenient fraction of a revolution may intervene between the ends of the strokes of the cylinders. As regards the theoretical efficiency of the steam the compound engine possesses no advantage over an engine with a single cylinder of the dimensions of the low-pressure cylinder, working with the same pressure of steam and the same rate of expansion." In pointing out the advantages which the compound engine possesses the following are referred to:—First, in point of strength the action of the steam when at its highest pressure takes place in the compound engine upon a comparatively small piston, thus diminishing the amount of the greatest straining force exerted on the mechanism and framing; secondly, it is shown that for economy of heat a single-cylindered engine requires to be wholly jacketted so that the temperature may be kept up to that of the steam on admission; but in the compound engine the smaller or high-pressure cylinder only requires to be kept to this high temperature; and thirdly, economy of work is obtained through the equalizing of the strains by the piston-rods on the bearings.

The machinery employed in our large ocean steamers is now of a very massive description, the high and low-pressure cylinders being of large diameter and the steam pressure very high. The *Alaska* recently launched on the Clyde (1881) is supplied with engines working up to 10,000 horse-power, the pressure of steam being 100 lbs., the high-pressure cylinder being 68 inches and the low-pressure cylinders 100 inches in diameter, the stroke being 6 feet.

The arrangements for direct-acting horizontal engines are various. In some examples the small cylinder is placed on the same centre line as the large one, bracketed or fitted to the cover of the latter, with one piston rod common to both pistons. In other arrangements an annular cylinder is placed around the small high-pressure one; this plan requires a long crosshead for taking the central or high-pressure piston rod, while there are two piston rods for the annular piston, one on each side of the high-pressure one, the connecting rod joining the crosshead directly to the cranked shaft, while in the former plan the connecting rod can be either direct or on the return principle. Some makers have introduced a sort of large hollow cast-iron piston rod, having a piston at each end; this great rod is kept steam-tight by an internal stuffing box, placed at the centre length of the cylinder. This arrangement, therefore, is simply two cylinders placed back to back formed in one casting, the two central cylinders being the high-pressure ones, while the low-pressure cylinders are at each end; or, more correctly writing, the high and low pressure principle is carried out in one cylinder common to both. A single-acting engine on this mode of construction would be simply a single trunk engine, the trunk end being for the high pressure and the other end for the low pressure. The power, however, is better equalized by adopting the trunk engine in duplicate, as described above; and this arrangement can be worked direct, or return connecting rods may be adopted for marine purposes. As the cylinder is double the length of the ordinary arrangements, the latter plan is adopted to suit fine midship sections.

In some examples of combined engines the high-pressure cylinder is placed on the top of the large cylinder, and connected by means of a rocking beam. Although the valves are greatly simplified in this plan, yet it cannot be considered a good one. When the pistons work in opposite directions, the steam expands from the one to the other, and the OUT stroke expansion of the small cylinder is taken up by the IN stroke of the large cylinder, and *vice versa;* but when the small piston is attached directly to the large one, the OUT stroke expansion of the small cylinder is taken up by the OUT stroke of the large one, thus entailing long steam passages between them, not to be desired. To obviate the objections to the short rocking beam, spur-wheel gearing has been introduced, having separate cranked shafts for each cylinder. This plan, however, involves complication, and is not needed, for when the high-pressure cylinder is placed alongside of the low-pressure one, as in the ordinary horizontal engine, such an arrangement meets all the requirements, and as simplicity on board ship is the main thing to study, the reduction of the wear and tear becomes of the first importance.

In reference to this point attention may be drawn to the vertical class of engine, more especially adapted for the mercantile marine, so successfully constructed by various engineering firms. The platform space occupied by these engines is not so great as that required for the horizontal type, and the wear and tear is greatly diminished, vertical pistons, valves, &c., keeping longer in good working order than those lying on their side,—a fact now beyond dispute. In the ordinary arrangement of this class of engine, the cylinders are supported overhead on a cast-iron framing securely bolted to the bed plate, on which is cast the pillow blocks for the cranked shaft. The cylinders are arranged the same as for inside-cylinder locomotive engines with the valves placed between the cylinders, thus placing the valve gear centrally and greatly simplifying the mechanism for working the valve. This engine, strictly speaking, is not of the direct-acting type, as the air pumps in most cases are worked by a rocking beam for each; when so fitted the descent of the pistons and adjuncts is in a measure balanced by the column of water lifted by the pump. This is a great advantage, and is decidedly to be preferred to the direct mode of working the air pumps from the piston by a rod passing through the bottom of the cylinder and attaching to it the air-pump bucket.

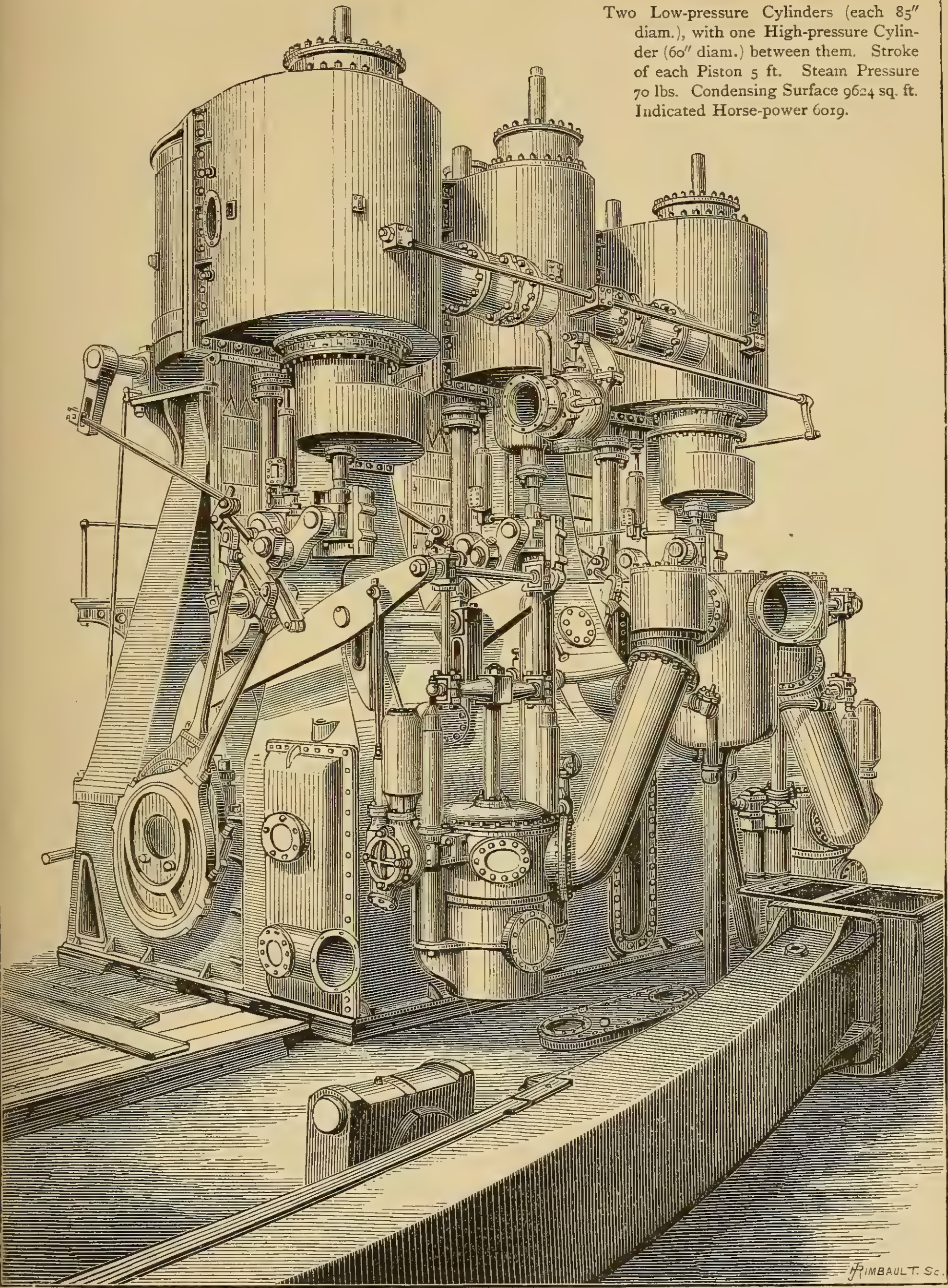
For engines of small power eccentrics have been successfully adopted for working air pumps lying in a horizontal position, but the plan is not nearly so effective as a means of balancing the machinery as working the pumps by the rocking lever already described, with links in connection with the crosshead of the piston rod at one end and the crosshead of the air pump at the other end.

The arrangements for compound engines of the vertical class are similar to those for single engines of the same class. The cylinders are supported from the top of the surface condenser on the one side, and there are cast-iron frames on the other; in some cases wrought-iron columns are introduced. The high-pressure cylinder is fitted to the side of the low-pressure one, and connected by means of a rocking beam for each; thus the pistons travel in opposite directions, and the valve gear is simplified as in horizontal arrangements. Some engineers place the high-pressure cylinder on the top of the cover of the low-pressure one, with one piston rod common to both pistons.

Theoretically and practically, direct action is correct, as the steam from the one cylinder is immediately taken up by the other; but the complication of the parts is an evil to be avoided, and engines are now introduced having the minimum of working parts. These engines consist of one high-pressure cylinder and a low-pressure one. The cranks in some examples are at right angles or 90°, in others the crank centres are 135° apart (and even, going to extremes, in a line with each other), with which the crank for the low-pressure cylinder leads, thus the piston being met by the expanding steam from the high-pressure cylinder, it is cushioned at each end of the stroke—a point necessary in all engines having a high rate of piston speed. When the cranks are placed at right angles, the exhaust steam is admitted into a compartment, generally taking the form of a casing around the cylinder, before it is expanded into the large cylinder. This plan is necessary to reduce the back pressure on the small piston; besides, the large piston is not in a proper position at the ending and returning of the high-pressure piston fully to utilize the steam. The large piston, too, must travel a little more before the expanding steam can be admitted into the cylinder.

In the large vessels recently built three cylinders are commonly adopted, two large and one smaller, the cranks being placed at 120°. See Plate of the engines of the S.S. *Parisian.*

ENGINES OF STEAM-SHIP "PARISIAN."


Two Low-pressure Cylinders (each 85″ diam.), with one High-pressure Cylinder (60″ diam.) between them. Stroke of each Piston 5 ft. Steam Pressure 70 lbs. Condensing Surface 9624 sq. ft. Indicated Horse-power 6019.

HRIMBAULT. Sc.

THREE-CYLINDER COMPOUND INVERTED ENGINES OF STEAM-SHIP "PARISIAN,"
5359 TONS GROSS.

CONSTRUCTED BY MESSRS. ROBERT NAPIER AND SONS, GLASGOW, FOR THE
ALLAN LINE OF ROYAL MAIL ATLANTIC STEAMERS.

The engines are three-cylinder compound inverted-cylinder type, working cranks set equal distances apart, that is 120°; the high-pressure cylinder is placed between the two low-pressure cylinders, into which its exhaust steam is led by means of two brass pipes attached to the valve casings.

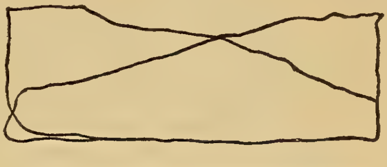


Fig. 373A.—High Pressure.

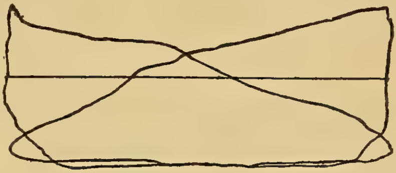


Fig. 373B.—Aft Low Pressure.

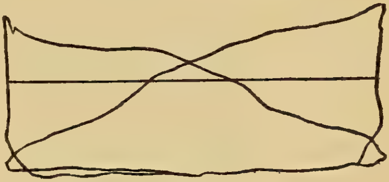


Fig. 373C.—Forward Low Pressure.

Indicated Diagrams from Engines of Screw Steamer "Parisian."

Steam 70 lbs., Vacuum 29, Revolutions 83·7.

The admission of steam to each cylinder is regulated by means of a piston valve, worked by a rocking shaft and levers, which are in turn driven by means of double eccentrics and link from the crank shaft.

The crank shaft is a "built-up" one of steel, and in three distinct pieces coupled together with flanges and bolts.

The surface condenser contains 9624 square feet of condensing surface. Two air pumps are bolted on the back of the condenser, and worked, along with the feed and bilge pumps, by means of levers and links from the low-pressure cylinder crossheads. The circulating pumps consist of two centrifugal pumps, each worked by separate engines.

The high-pressure cylinder is 60 inches diameter × 5 feet stroke. Each low-pressure cylinder is 85 inches diameter × 5 feet stroke.

The engines of the *Servia* and *City of Rome*, the largest ships afloat excepting the *Great Eastern*, are also of the compound inverted type, those of the *Servia* working up to about 10,000 indicated horse-power. The *Alaska's* engines are also capable of working up to this high figure.

It may seem strange to pass high-pressure steam through the small cylinder, and reduce the pressure before it enters the large cylinder; but we must take into consideration that when the cranks are placed at right angles to each other, the engines are found to be more easily handled, while it is necessary, as before described, to reduce the back pressure on the small piston: this deviation from what theory points out as correct is successfully adopted in practice. To meet theory on the one hand, and overcome the difficulty of starting the engine on the other, the cranks have been placed farther apart; thus the expanding steam from the high-pressure cylinder is sooner picked up by the low-pressure piston, while the large piston is properly cushioned, which would not be the case were the crank centres directly opposite each other —a position in which it is very difficult to start the engines, although

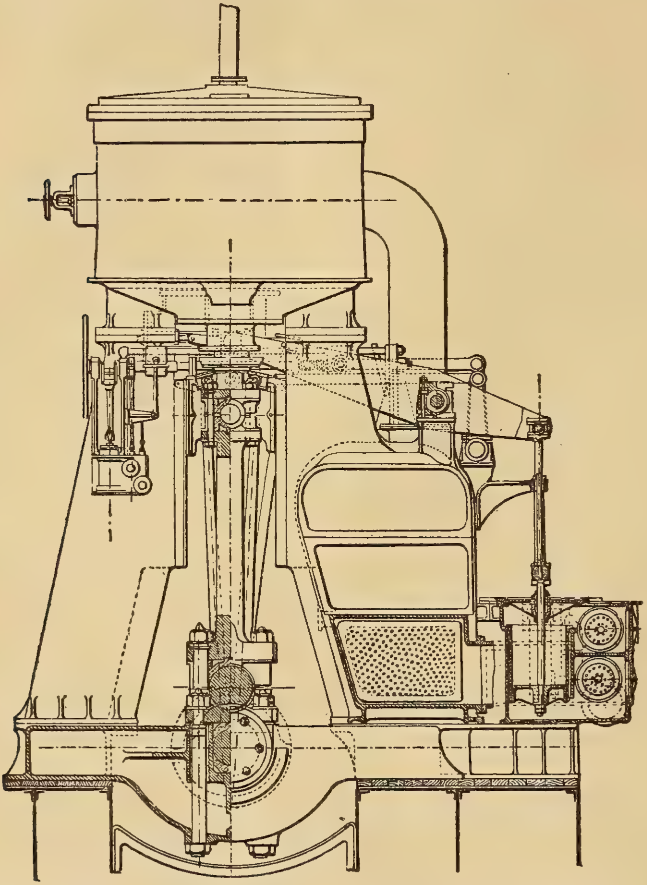


Fig. 374.—Compound Marine Engines, by Fawcett, Preston, & Co., Liverpool, fitted on board the Screw-ship "Itata." Sectional End Elevation.

when once set in motion they work pretty well, but on the whole not so steadily as in the intermediate position. The air pump and circulating pump are worked by rocking levers for large power; while for small power, eccentrics are used to give motion to the pistons of the pumps.

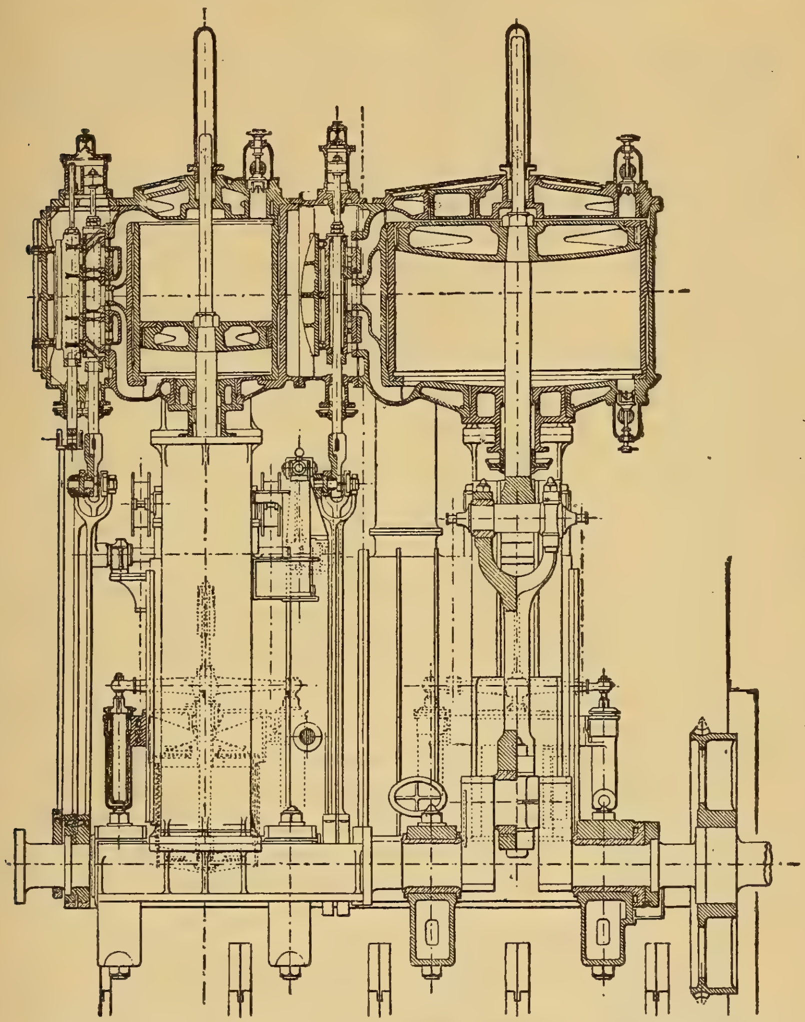


Fig. 375.—Compound Marine Engines, by Fawcett, Preston, & Co., Liverpool, fitted on board the Screw-ship "Itata." Sectional Side Elevation.

SCREW STEAMSHIP "SERVIA." Gross Tonnage 7400, nett 3900 tons.

(See Plate.)

The Engines are of the three-cylinder compound direct-acting arrangement; one high-pressure cylinder of 72 inches diameter and two low-pressure cylinders of 100 inches diameter each, and 78-inch stroke of piston; the valves for high pressure are piston valves, and those for low pressure slide valves, with four ports, as shown on plans. The surface condensers (two) are placed fore and aft, forming part of support for the cylinders; they can be worked together or separately; the circulation of water is effected by two of J. & H. Gwynne's 20-inch Invincible pumps; the air and feed pumps are worked off lever on low-pressure engines. The crank shaft is in three pieces, of Vicker's steel, and is 25 inches diameter. The propeller is 24 feet diameter, and the boss and blades are of Vicker's steel. The starting gear is Brown's patent steam and hydraulic gear.

Steam is supplied to the engines by seven Boilers, six of these double-ended, with six furnaces in each, and one single-ended with three furnaces, in all thirty-nine furnaces, of 4 feet 2 inches diameter and 6 feet 9 inches long; the total effective grate surface being 1050 square feet, and the total heating surface 27,000 square feet. The boilers are of oval form, 14 feet 10 inches wide, 18 feet high, and 18 feet 3 inches long.

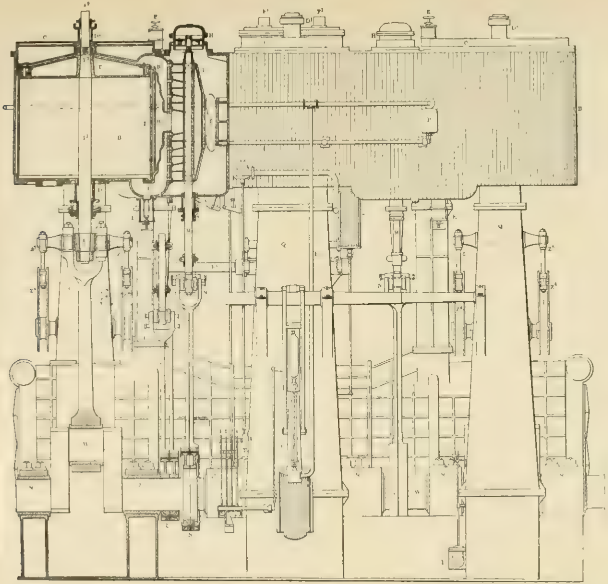
The engines on trial developed 10,500 I. H. P., and the speed at sea 17¼ knots per hour. The dimensions of the ship are: Length over all, 530 ft.; breadth, 52 ft.; depth from top of keel to top of upper deck beams, 42 ft. The *Servia* crosses the Atlantic in little over seven days, consuming 1300 tons of coal on the passage.

SCREW STEAMSHIP "ITATA." Tonnage 2391 B.M.

See Figs. 374 and 375, pages 498, 499.

The Engines, of 340 nominal horse-power, have one high-pressure cylinder 3 ft. 10 in. diameter, and one low-pressure cylinder 7 ft. 2 in. diameter; length of stroke 3 ft. 6 in. Number of tubes in surface condenser 1164, diameter 1 inch. Diameter of circulating pump 1 ft. 8 in., stroke 1 ft. 9 in. Diameter of air pump 2 ft. 8 in., stroke

ENGINES OF STEAM-SHIPS "UMBRIA" AND "ETRURIA."

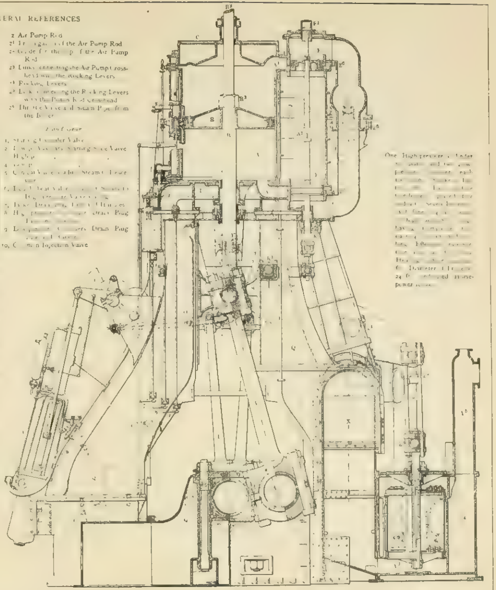


EXPLANATION OF LITERAL REFERENCES

A	High pressure Cylinder with Steam Jacket
A¹	Steam Ports
A²	Exhaust Passage to the Low pressure Cylinders
B B	Low pressure Cylinders with Steam Jackets
B¹	Steam Ports
B²	Exhaust Passage to the Surface Condenser
C	Cylinder Covers
C C	Stuffing boxes and Glands for Piston Rods
C¹ C¹	Stuffing Boxes and Glands for prolonged Piston Rod
E E	Escape Valves
F F	Piston Valves for the High pressure Cylinder
F¹	Piston for carrying up the weight of the Valves
G	Slide Valve for the Low pressure Cylinders
G¹	Piston for carrying up the weight of the Valve
[illegible]	Spring on the back of the Valve
K	High pressure Valve Spindle, Link and Levers in connection with the Double Eccentrics and Link Motion for the High pressure Cylinder
K¹	High pressure Piston Valve Rocking Shaft
L	Double Eccentrics and Link Motion for the High pressure Valves
M M	Valve Spindles for the Low pressure Cylinders
N N	Double Eccentrics and Link Motion for the Low pressure Cylinder Valve
O	Steam and Hydraulic Starting Gear, with Shaft, Lever and Rods in connection with the Link Motion
P	Auxiliary Starting Valve
P¹	Steam Pipe
Q	Main Framing for supporting the Cylinders
Q¹ Q¹	[illegible] for the Crosshead of [illegible] the High pressure Cylinder
R	Piston Rod
R	[illegible]
S	Nut for [illegible] Crosshead and [illegible]
[illegible]	Piston of the Low pressure Cylinder
T	Piston Rod
T¹	Prolongation of the Piston Rod
T	[illegible] the Piston
U	Crosshead and Gudgeon
V V	Connecting Rods
W	Crank and Crank Shaft
X	Surface Condenser
Y	Air Pump
Y	Cover
Y	[illegible]
Y	Head Valves
Y¹	Hot Well
Y²	Air Pump Discharge Pipe
Z	Air Pump Rod
Z¹	Prolongation of the Air Pump Rod
Z²	Guide for the top of the Air Pump Rod
Z³	Links connecting the Air Pump Crosshead with the Rocking Levers
Z⁴	Rocking Levers
Z⁵	Links connecting the Rocking Levers with the Piston Rod Crosshead
Z⁶	Throttle Valve and Steam Pipe from the Boiler

Hand Gear.

1,	Starting Cylinder Valve
2	[illegible] Starting Slide Valve High pressure [illegible]
4	[illegible]
5	Circulating [illegible] Steam [illegible]
6,	[illegible]
7,	[illegible]
8	High pressure [illegible] Drain Plug [illegible]
9	Low pressure Cylinders Drain Plug [illegible]
10,	Common Injection Valve



One High pressure Cylinder [illegible] and two Low pressure [illegible] each [illegible] Diameter [illegible] 24 [illegible] indicated Horse-power [illegible]

THREE-CYLINDER COMPOUND DIRECT-ACTING ENGINES OF STEAM-SHIPS "UMBRIA" AND "ETRURIA."

CONSTRUCTED BY MESSRS. JAMES AND GEORGE THOMSON, GLASGOW, FOR THE CUNARD LINE OF ROYAL MAIL ATLANTIC STEAMERS.

1 ft. 9 in. Diameter of feed and bilge pumps (two of each) 6 in., stroke 1 ft. 9 in.

There are four Boilers, each 9 ft. 7 in. in length, and 11 ft. 6 in. diameter. Each boiler has three furnaces, of 3 ft. diameter. The total heating surface is 5140 sq. feet. Pressure 70 lbs.

The diameter of the screw propeller is 16 ft. 6 in., the varying pitch 24 ft. to 27 ft.

The feed steam pumps, of which there are two, have each a cylinder of 8 inches diameter and 9 inches stroke, driving a double-acting pump 4 inches in diameter. They are arranged to draw water from either the sea or the bilges, and to discharge into the boilers, on deck, or into the sea, as may be desired. There is also a ballast steam pump, with a cylinder 7 inches in diameter and a stroke of 9 inches, driving a double-acting pump of 9 inches in diameter, which draws the water from the fore and aft ballast compartments. A double-acting hand pump is also provided, having a diameter of 7 inches and a stroke of 15 inches, which can also be worked from the main engines.

The *Itata* has a length over all of 305 ft., breadth of beam 40 ft., and depth under main deck of 19 ft. 6 in. The average consumption of fuel during a voyage of this ship from Liverpool to Valparaiso was only 1·007 ton per hour of steaming, and taking the indicated horse-power as 3½ times the nominal horse-power, we have a coal consumption of under 2 lbs. per indicated horse-power.

SCREW STEAMSHIP "SIR BEVIS." Tonnage 919 B.M.

See Figs. 376, 377, 378, pages 502–504.

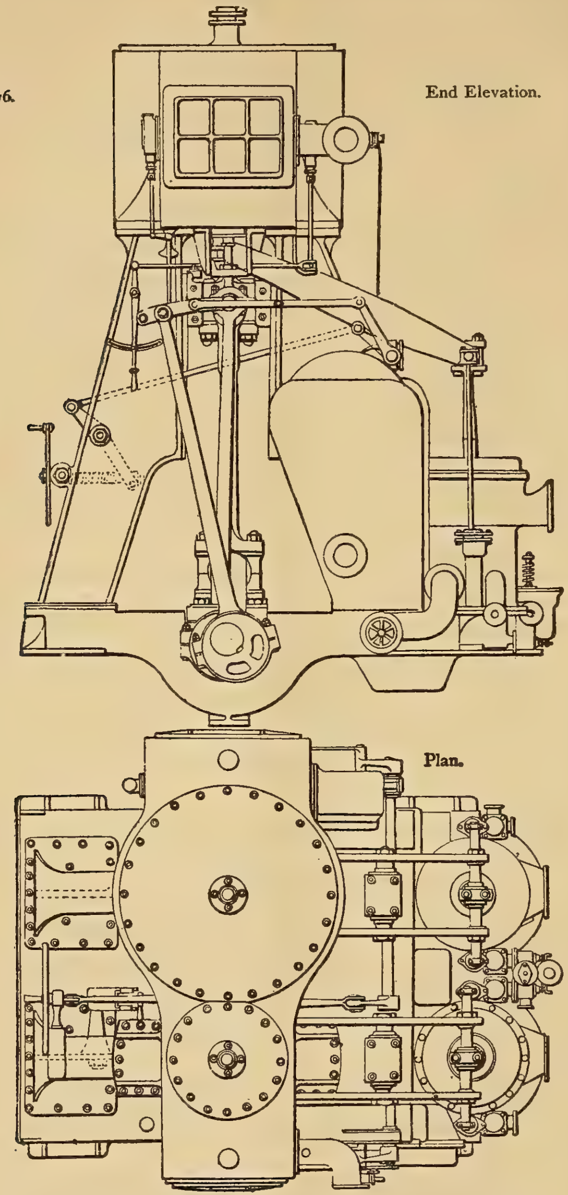
The Engines, of 115 nominal horse-power, have one high-pressure cylinder 2 ft. 2 in. diameter, and one low-pressure cylinder 4 ft. 4 in. diameter; length of stroke 3 ft. The surface condenser has 944 tubes, 6 ft. long and ¾ in. diameter; condensing surface of tubes 1112 sq. feet.

The Boilers are cylindrical, with a total heating surface of 1982 sq. feet; area of fire grate 65 sq. feet. Steam pressure in boiler 60 lbs. per sq. inch.

The diameter of the screw propeller (four-bladed) is 13 ft. 4 in., the varying pitch 16 ft. to 18 ft. The *Sir Bevis* has a length over all of 210 ft., breadth of beam 30 ft., depth 17 ft.

The vessel has a carrying capacity of 1020 tons of dead weight, of which 120 tons of coal is carried in the bunkers. Thus loaded she has steamed at an average rate of 9 knots per hour, with an

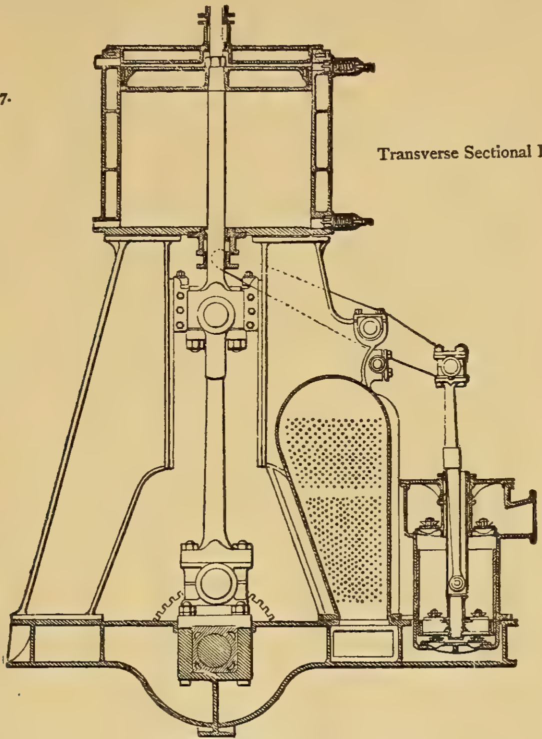
Fig. 376.



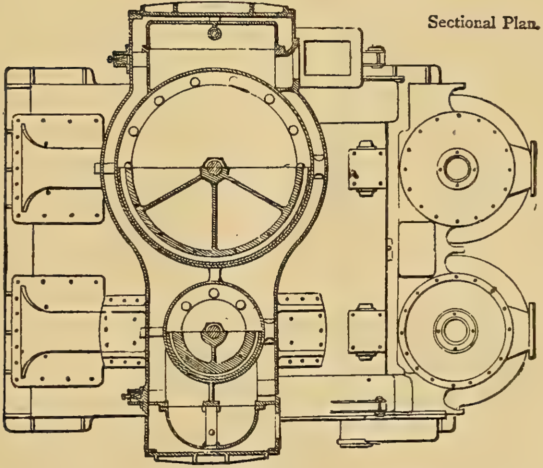
Figs. 376, 377, 378.—Compound Engines for the Screw Steam-ship "Sir Bevis." Constructed by Messrs. Day, Summers, and Co., Engineers, Southampton.

average consumption of 7 tons 12 cwts. 0 qr. 12 lbs. of Newcastle coal per twenty-four hours; and as the average indicated horse-power is 360, this gives 1·9 lb. per hour as the consumption of fuel.

Fig. 377.

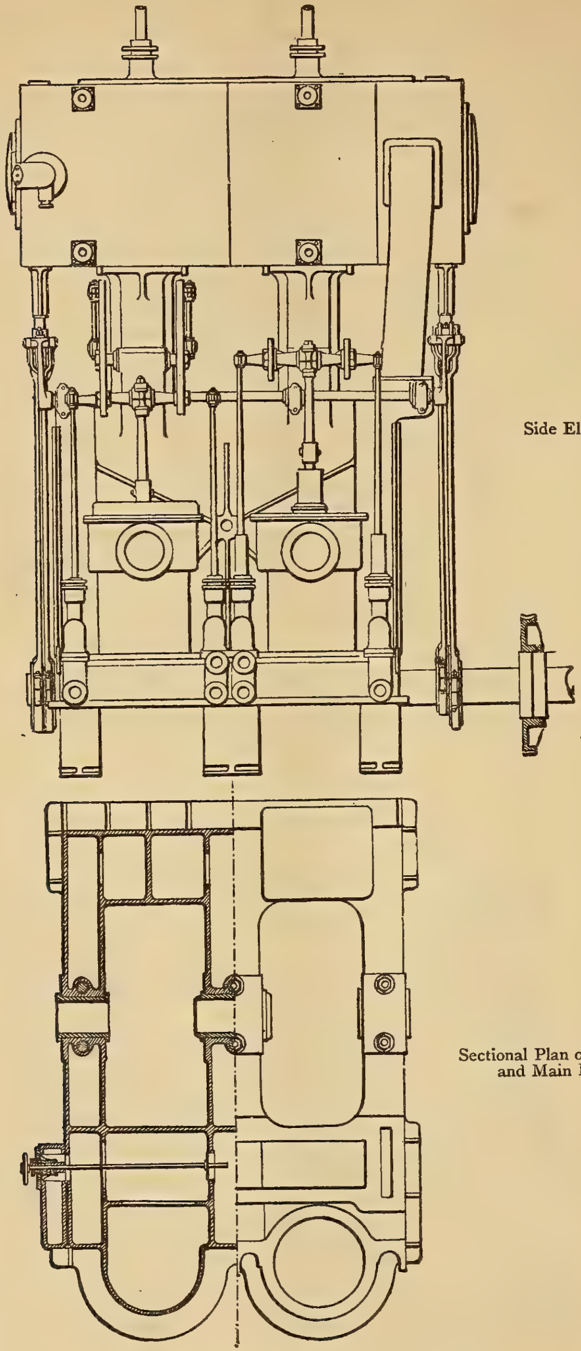


Transverse Sectional Elevation.



Sectional Plan.

Fig. 378.



Side Elevation.

Sectional Plan of Condenser and Main Frame.

The S.S. *Arizona*, built in 1879 for the Guion line by Messrs. Elder & Co. of Glasgow, is a good type of the fast ocean steamers of the present day. She measures 465 ft. in length by 45 ft. 6 in. breadth, and 37 ft. 6 in. deep, the tonnage being 5146. The engines developed on trial 6357 indicated horse-power with 56 revolutions per minute; the speed being 17·3 knots per hour.

The engines are compound with three inverted cylinders. The high-pressure one is 62 inches diameter, and the two low-pressure ones 90 inches diameter each; the stroke is 5 feet 6 inches; the slide valves are of the piston equilibrium form; the surface condenser has a cooling area of 12,540 sq. ft., the water being circulated by two large centrifugal pumps; the crank shaft is "built," and is 22½ inches diameter (see p. 415); the propeller is 23 feet diameter with steel blades.

There are one single-ended and six double-ended boilers, of a diameter of 13 feet 6 inches, and length of 18 feet for the double-ended and 10 feet for the single-ended. These are fitted with 39 furnaces 3 feet 3 inches diameter, having a grate area of 780 sq. feet and a total heating surface of 19,500 sq. feet. The shell plates are 13/16" thick, the working steam pressure is 90 lbs.

GOVERNORS.—As the piston speed varies greatly in marine engines when the vessel pitches in rough weather, causing a severe strain both to the engines and hull, governors have been introduced to regulate the supply of steam to the cylinders, and so prevent what is technically termed "racing" of the engines, due to the screw being only partly submerged when the vessel is pitching. Governors should be exceedingly sensitive, and quick in acting upon the valve for throttling as it were the steam in its passage to the cylinders, when the pistons have a tendency to sudden acceleration of speed.

Various forms have been tried, as the four-ball, the fly-wheel, fly-wheel fitted with vanes, &c., and others. The first-mentioned form acts as an ordinary ball governor, the four balls being introduced to remedy an evil felt with the ordinary two-ball arrangement, which did not act in a satisfactory manner owing to the motion of the vessel. The arrangement consists of a spindle taking two arms which cross each other, and are jointed with one pin passing through a jaw on the spindle; on each end of the arm a ball is fitted, by this means balancing the pendulum arm of the governor. The spindle is fitted with a sliding collar, and is connected to the pendulum arms with two links, and there is a spiral spring bearing on the collar, to regulate its return action, while at the other end of the collar is fitted a lever and rod communicating with the throttle valve. This governor is carried in a suitable frame, and is driven by a band passing round a pulley fitted to the revolving spindle, the whole arrangement lying horizontally.

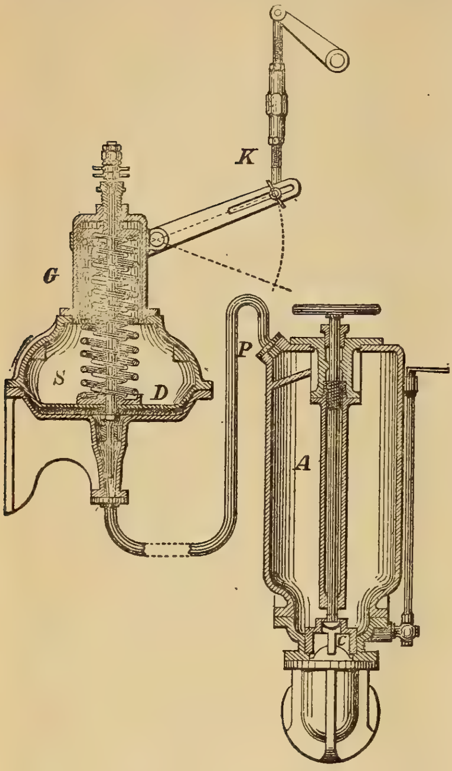


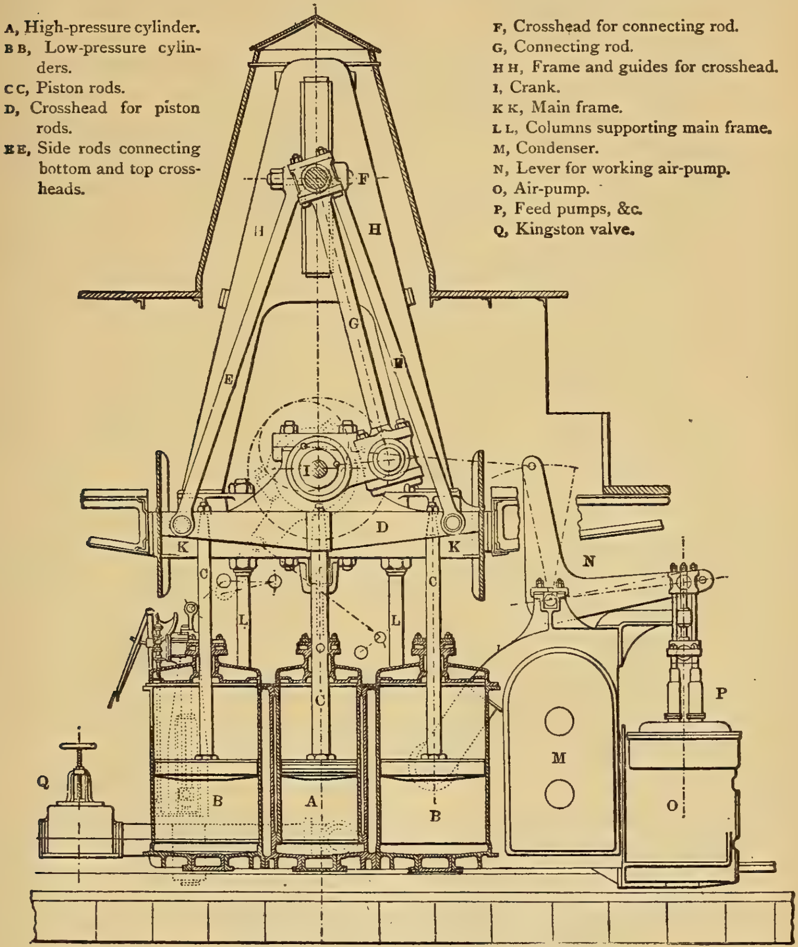
Fig. 378A.—Dunlop's Pneumatic Marine Governor.

Fig. 378A shows Dunlop's Pneumatic Marine Governor, which has been found very serviceable for compound marine engines. In this governor the controlling power lies in the level of the water outside the ship, as this varies from time to time with the pitching of the vessel.

A is an air vessel, which is placed in communication with the sea by the valve C. The air becoming compressed the action is communicated to the governor G, which consists of a casing containing an air-tight space in connection with the pipe P and fitted with an india-rubber diaphragm D. This diaphragm, as it rises and falls due to the pressure of the air as acted upon by the varying level of the waves, acts upon the spring S, which motion is communicated to the throttle valve by means of the link K.

Fig. 378B shows an arrangement of Compound Engine which appears to have been applied successfully for paddle-wheel steamers. It is illustrated and described in a paper read by Mr. F. C. Marshall, at a meeting of the Institute of Mechanical Engineers, held in Newcastle in 1881, in which he shows that such engines may be grouped in three typical forms, viz.:—

1st. The two-cylinder intermediate receiver compound engine having cranks at right angles. 2d. The Woolf engine in the tandem form, having generally the high-pressure and low-pressure cylinders in line, but occasionally alongside, and always communicating their power to one crank. 3d. The three-cylinder intermediate receiver compound engine with one high- and two low-pressure cylinders, the steam passing from the high-pressure cylinder into the receiver, and thence into the two low-pressure cylinders respectively.



A, High-pressure cylinder.
B B, Low-pressure cylinders.
C C, Piston rods.
D, Crosshead for piston rods.
E E, Side rods connecting bottom and top crossheads.
F, Crosshead for connecting rod.
G, Connecting rod.
H H, Frame and guides for crosshead.
I, Crank.
K K, Main frame.
L L, Columns supporting main frame.
M, Condenser.
N, Lever for working air-pump.
O, Air-pump.
P, Feed pumps, &c.
Q, Kingston valve.

Fig. 378B.—Three-cylinder Compound Steeple Engine for the Paddle.

The arrangement shown by Fig. 378B is of the three-cylinder class. The steeple form of engine is adopted; the three cylinders of each engine being bolted to each other and to the keelsons.

AVERAGE CONSUMPTION OF COAL, PER INDICATED HORSE-POWER PER HOUR,

(See Mr. F. C. MARSHALL'S Paper "On the Progress and Development of the Marine

ENGINES.								BOILERS.					
No.	Class.	Cylinders.			Piston Speed per Min.	Condensing Surface.	Diameter of Screw Propeller.	Working Pressure above Atmosphere.	Number of Boilers.	Shell.		Furnaces.	
		Diam.		Stroke.						Diameter.	Length.	Total No.	Diameter.
		High Press.	Low Press.										
		In.	In.	In.	Ft.	Sq. Ft.	Ft. In.	Lbs.		Ft. In.	Ft. In.		Ft. In.
1	A	34	61	45	450	2466	15 3	70	2	12 0	15 0	8	3 6
2	A	42	80	48	552	..	..	72·5	2	13 6	18 6	..	..
3	A	35	70	48	400	2400	17 0	90	2	11 6	18 6	8	3 6
4	A	46	87	57	484	5000	19 0	80	3	12 3	18 6	12	3 9
5	A	22	44	30	360	705	11 0	100	1	12 8	11 6	3	3 0
6	A	50	86	54	540	4865	17 6	72	4	W13 4½ H16 0¾	10 0¾	12	3 6
7	A	35	70	48	424	2000	17 0	90	2	9 6	18 6	8	3 6
8	A	54	94	60	530	7420	18 3½	75	6	12 9	10 6	18	3 2
9	A	54	94	60	486	7422	18 0	82·5	6	12 9	10 6	18	3 2
10	A	30	58	39	400	1518	14 2	80	2	12 0	10 6	4	3 2
11	A	29	56	33	350	1250	13 3	70	2	11 0	10 6	4	3 0
12	A	34	66	42	406	1700	15 6	80	2	13 4	10 6	6	3 3
13	A	36	68	42	434	1821	16 3	77	2	14 4½	10 3	6	3 4
14	A	54	97	60	480	7427	18 10½	70	6	15 10½	10 6	18	3 2
15	A	51	88	60	590	5000	17 6	75	4	W15 6 H18 6	10 9	12	4 2
16	A	28	53	38	380	1560	14 0	75	2	12 1	9 5	4	3 3
17	A	50	86	54	540	5500	17 6	70	4	W13 8 H17 3	10 0	12	3 6
18	A	38	70	48	416	2600	17 9	80	..	..	..	..	..
19	A	35	70	48	408	2005	17 0	90	2	11 6	18 6	8	3 5
20	A	35	70	48	440	2000	20 9	90	2	10 11	18 6	8	3 3
21	A	34½	64	42	500	1647	15 4	80	2	9 6	13 0	8	2 8
22	A	48	84	60	550	4468	19 0	70	3	W11 9 H14 3	16 6	18	3 2
23	A	50	86	54	510	4842	17 9	70	6	11 3¼	9 10	18	3 0
24	A	54	94	60	441	7420	17 9	70	6	12 9	10 6	18	3 2
25	A	56	97	54	504	5000	18 6	70	6	13 0	10 3	18	3 3
26	A	30	60	36	372	1600	13 0	90	2	11 3	9 7	6	3 2½
27	A	36	70	45	560	2900	13 0	75	2	13 0	14 0	12	3 1
28	A	36	64	36	450	2059	13 0	70	2	13 0	9 4	6	3 2
29	A	36	68	42	530	2500	13 0	70	2	14 0	11 0	6	3 6
30	A	36	67	42	530	2400	13 0	70	2	14 0	11 0	6	3 6
Mean					**467**			**77·4**					
31	C	48	83	60	523	9000	23 6	70	8	W14 4½ H 9 0	19 10	32	3 3
32	B	26	58	45	444	1700	15 0	80	2	13 4	9 6	6	3 0
33	B	27	56	52	395	1730	15 9	80	1	W12 0 H14 2	24 0	6	3 4
34	B	27	56	52	412	1650	15 9	75	1	..	..	6	3 4
35	C	28	60	54	504	4100	20 0	90	3	11 6	17 6	18	2 10
36	C	28	60	54	522	4100	20 0	80	3	11 6	17 6	18	2 10
37	C	16	34	30	360	768	12 6	68	1	11 6	9 10	3	3 2
38	C	26	52	42	336	2400	17 3	70	2	10 9	17 0	8	3 1
Mean					**437**			**76·6**		W=Width H=Height			
39	D	62	90 90	66	605		21 0	90	7	13 6	six 18 0 one 10 0	39	3 3

Class A—Compound Engines with one High and one Low-pressure vertical
,, B ,, one ,, one ,, ,,
,, C ,, two ,, two ,, ,,
,, D ,, one ,, two ,, ,,

* Always working with early cut-off; engines never pressed; Welsh coal.

BY STEAM SHIPS WITH COMPOUND ENGINES IN LONG SEA VOYAGES.

Engine," read at meeting of Inst. Mechanical Engineers, held at Newcastle, 1881.)

BOILERS.									PERFORMANCE.			
Tubes.				Total Fire-grate Area.	Heating Surface.			Heating Surface per I.H.P.	Indicated Horse Power.	Coal Consumption.		Heating Surface per lb. of Coal per Hour.
Total No.	Length.		Outside Diam.		Tubes.	Furnaces, &c.	Total.			In 24 Hours.	Per I.H.P. per Hour.	
	Ft.	In.	In.	Sq. Ft.	Sq. Ft.	Sq. Ft.	Sq. Ft.	Sq. Ft.	I.H.P.	Tons.	Lbs.	Sq. Ft.
800	6	0	3	140	3688	528	4216	4·68	900	14·5	*1·50	3·12
..	..		..	..	..	..	6000	3·19	1881	32·25	1·60	1·993
640	6	10	3½	160	3814	626	4440	3·7	1200	21	1·63	2·265
1164	6	7	3¼	250	6420	1383	7803	3·545	2200	40	1·66	2·136
172	7	3	3¼	49·5	1060	342	1402	3·34	420	7·5	1·67	2·0
1024	7	0	3½	273	6530	1192	7722	2·88	2677	48	1·67	1·725
608	6	10⅜	3½	150	3822	952	4774	3·97	1200	21·5	1·69	2·35
1308	7	6	3½	313	8983	1856	10839	4·9	2207	40·3	1·7	2·88
1266	7	6	3½	324	8735	2605	11340	6·3	1801	32·8	1·7	3·705
344	7	3	3¼	69·64	2120	488	2608	4	650	12	1·72	2·34
316	7	0½	3¼	66·0	1891	488	2379	4·74	500	9·5	1·76	2·69
352	7	3	3½	107·25	2708	766	3474	3·975	875	16·5	1·76	2·27
460	7	0	3½	110	2950	764	3714	4·34	854	16·75	1·763	2·46
1314	7	6	3½	329	9198	1847	11045	5·52	2000	38·6	1·80	3·065
1224	7	0	3½	332·5	7850	1398	9248	3·365	2745	54	1·83	1·839
328	7	0	3½	78	2050	383	2433	4·34	560	11	1·84	2·36
1016	7	0	3½	273	6393	1132	7525	3·105	2422	48	1·85	1·647
..	..		..	65	..	..	4864	4·18	1160	23	1·85	2·26
616	6	10⅜	3½	150	3872	954	4826	4·39	1099	22	1·87	2·35
544	6	9	3½	136	3384	1012	4396	3·875	1135	23	1·89	2·05
368	6	9	3½	106	2332	618	2950	3·35	880	18	1·90	1·762
1140	6	9	3½	340	7153	1047	8200	3·56	2300	47	1·90	1·873
1188	7	0	3½	310	7603	2236	9839	4·44	2213	43·5	1·90	2·34
1326	7	6	3½	312	9149	2601	11750	4·9	2400	48·9	1·90	2·58
1062	7	3	3½	292	6913	1302	8215	3·282	2500	51 9	1·93	1·70
360	6	8	3½	115	2230	523	2753	4·59	600	12·5	1·945	2·36
912	5	4	3	166	3884	738	4622	2·88	1600	32	†2·0	1·44
380	6	4	3½	106	2272	582	2854	2·795	1020	22	†2·125	1·315
408	7	0	3½	130	2876	586	3462	2·77	1250	29	†2·25	1·23
..	7	0	3½	129	2866	585	3451	2·8	1230	28	†2·25	1·243
								3·917			**1·828**	**2·178**
2432	7	2	3½	624	15783	3321	19104	3·9	4900	93	1·77	2·2
472	6	6	3¼	99	2566	594	3160	3·85	820	16·75	1·90	2·026
284	9	0	4	102	2675	569	3244	4·45	730	15·1	1·92	2·32
296	9	0	4	102	2750	820	3570	4·63	771	16	1·93	2·4
1116	6	6	3¼	300	6165	1235	7400	3·89	1900	40	1·96	1·986
1116	6	6	3¼	302	6171	1243	7413	4·0	1850	40	2·01	1·95
150	6	6	4	47·25	1004	346	1350	5·0	270	7	2·25	2·22
544	6	1	3½	132	3033	617	3650	4·06	900	24	2·47	1·641
								4·22			**2·026**	**2·096**
2522	7	0	3½	780	16200	3300	19500	3·09	6300	137	2·035	1·52

Cylinder, working two cranks at right angles.
,, one crank. Cylinders in line (tandem).
,, two cranks at right angles. Cylinders in line (tandem).
,, three cranks at 120°.

† These four ships are very limited in boiler power.

The preceding table of results from recent practice with the marine engine is a valuable and interesting one, and not the least important part of its information is that showing the relations existing between some of the more particular parts when compared with each other, and with the power developed by the engines. Thus it is shown that the heating surface is about 4 sq. ft., and the condensing surface about 2 sq. ft. per indicated horse-power. Again, the consumption of coal is about 1·8 lb. per indicated horse-power per hour, and the heating surface is about 30 times the grate surface. The indicated horse-power appears to be about 8 times the grate surface, and the heating surface per lb. of coal per hour is about 2⅙ sq. ft.

RULES FOR THE HORIZONTAL DIRECT-ACTION MARINE ENGINE, &C.

Nominal horse-power.—For calculating marine engines a commercial unit is used, termed "nominal horse-power." A certain number of square inches of cylinder area, and a velocity of piston in feet per minute, are given; 7 lbs. per square inch being the recognized pressure, and 33,000 lbs. the duty of one horse-power per minute. Hence the formula—

$$\frac{\text{Area of cylinder in square inches} \times 7 \text{ lbs.} \times \text{feet per minute}}{33000} = \text{N.H.P.}$$

The indicated horse-power of an engine has nothing whatever to do with the nominal horse-power, and can only be found by means of an indicator diagram taken off the engine, from which the mean pressure on the piston is found, as explained in another part of this Work. The engine maker is often asked to give four, six, or even more times the nominal measure; and this can readily be calculated by giving a large steam pressure over that used for finding the nominal power, determining the point of cut off, besides taking into consideration the vacuum in the condenser, which may be put down in round numbers at 12 lbs. per square inch. Hence the formula—

$$\frac{\begin{array}{c}\text{Area of cylinder in}\\\text{square inches}\end{array} \times \left(\begin{array}{c}\text{Mean steam pressure}\\\text{per square inch}\end{array} + \begin{array}{c}\text{Vacuum per}\\\text{square inch}\end{array}\right) \begin{array}{c}\text{Velocity of piston attained}\\\text{in feet per minute}\end{array}}{33000}$$

gives the indicated horse-power, which is simply the actual power given off on the piston.

The power varies approximately as the cube of the speed of vessel (see p. 513).—A vessel of a certain form and tonnage, and of 200 horse-power, has a speed of 12 knots per hour, and we wish another vessel of the same lines and tonnage to attain a speed of 15 knots per hour: the cube of 12 is 1728, and of 15 is 3375; thus—

$$\frac{3375 \times 200}{1728} = 390 \text{ horse-power.}$$

Thus very nearly double the power is required to give an additional speed of 3 knots per hour to the vessel, and this is a serious matter when we remember that the amount of coal consumed is in the same ratio. For example: supposing the vessel had to steam over 3000 knots, going at a speed of 12 knots per hour it would take 250 hours to run the distance, and going at 15 knots per hour it would take 200 hours; therefore taking the horse-power as indicated, and the coal consumed per horse-power per hour at 2½ lbs., we have—

$$200 \times 2{\cdot}5 \times 250 = 125{,}000 \text{ lbs. of coal}$$
$$390 \times 2{\cdot}5 \times 200 = 195{,}000 \text{ lbs. of coal.}$$

or, in round numbers, 31 tons more coal is required to perform the same distance at the quicker rate of speed. In the construction of all steam vessels, respect must of course be had to the facilities for coaling at the stations on which they are intended to run, and their carrying capacity for coal adapted accordingly. Theoretically and practically it has been proved, under all circumstances, that a low rate of speed is the most advantageous in an economical point of view. Thus when ships of war are cruising at sea it is advisable to work the engines at half-power, or such a fractional part of the power as may be thought best under the circumstances; but on no account should the steam power be decreased in cases where the full power may be demanded at a moment's notice,—economy in coal being but a secondary consideration when the safety of the vessel is in question.

Proportion of power to tonnage.—In the merchant service the proportion of power to tonnage for vessels of about 2000 tons of tonnage ranges from 1 to 5·6 to 1 to 3·8; in a number of vessels, with a horse-power ranging from 80 to 700, the average proportion was 1 horse-power to 4·6 tons of tonnage. This is only the nominal or commercial horse-power allowed; but the actual or indicated horse-power depends on the lines and draught of water of the vessel, taking into consideration the speed that may be required.

To determine this point correctly the shipbuilder and engineer should work hand in hand; and by studying the lines and configuration of a particular class of vessel, with a knowledge of the power actually required to propel her at a certain speed, they may be able to adapt the power to the requirements of future vessels.

Rule for tonnage.—Multiply the length of vessel between perpendiculars, minus three-fifths of the breadth, by the square of the breadth divided by 2, and divide the result by 94 as a constant: the quotient gives the tonnage in old builders' measurement.

Performance of screw vessels.—To find the coefficient for screw ships, multiply the cube of the speed in knots per hour by the midship section of the vessel in square feet, dividing the result by the indicated horse-power: the quotient will be the coefficient of performance—the higher the number the better the result.

To find the speed with the coefficient, multiply the indicated horse-power the engine is intended to work to by the coefficient for the class of vessel, dividing the result by the area of midship section in square feet: the cube root of the quotient is an approximate of the speed the vessel will attain.

Another method for finding the coefficient of performance is to multiply the cube of the speed in knots by the cube root of the displacement in tons squared, and divide the result by the indicated horse-power. Hence the following formulas—

$$\text{(First method)}\ \frac{\text{Speed}^3 \times \text{midship section in square feet}}{\text{Indicated horse-power}} = \text{coefficient.}$$

$$\text{(Second method)}\ \frac{\text{Speed}^3 \times \text{displacement}^{\frac{2}{3}}}{\text{Indicated horse-power}} = \text{coefficient.}$$

For 14 knots per hour, the coefficient for ironclads by the former method—the length of the vessel being seven times its breadth—may be taken at 600 as a constant, and 500 when the vessel's length is five times its breadth. For the merchant service the coefficient varies according to the length of the vessel—the greater the length the better the coefficient becomes. For instance, the steamship *Cadiz*, with a proportion of length of eight beams, has a coefficient of 800; while in others, with a length of seven and three-quarter beams, it is about 662. It will thus be seen that long vessels are the most economical in carrying power, the speed attained being better than in a shorter vessel for the same indicated horse-power, while of course more stowage is afforded for cargo; and many screw steamships, after running for years, have been lengthened, with a view to gain these important advantages, whilst retaining their original engines and boilers.

The following extracts from a recent paper on this subject will show the conditions involved in this question.[1]

"It is an immediate consequence of the fundamental definitions of mechanics that if the gross indicated horse-power required to propel a vessel at the rate of V nautical miles per hour be denoted by E, then the gross resistances to the motion of that vessel is expressed by a quantity of the form $C\frac{E}{V}$, in which C is a coefficient dependent upon the construction elements and development of power in the engines, or, in an equivalent, but directly opposite point of view, the construction elements of the hull and circumstances affecting the expenditure of the developed power.

Now, a first approximate statement of the problem of steamship propulsion, according to mechanical principles as stated by Smeaton and other mechanicians, is furnished by the well-known formula, $C = \frac{M V^3}{E}$; sometimes termed the 'Admiralty Formula,' in which M is the immerged midship area, E the gross indicated horse-power corresponding to the trial speed, V nautical miles, and C, a numerical coefficient, which, in the cases where M, E, and V are known, is easily calculated, and which, subject to the following reservations, has been generally adopted as an approximate measure of the efficiency. It is found, however, in trying experiments on the same vessel at different speeds, where there would seem to be no good reason for supposing great variations in efficiency, the coefficients thus found vary in an extraordinary degree; also, in passing from one vessel to another, the variations have been found irregular, contradictory, and perplexing to a degree which, without the aid of other considerations, principally derived from experience of the values which have been obtained in vessels of similar dimensions and speed, would render these coefficients of doubtful value as a measure of efficiency; and, although a coefficient of efficiency is undoubtedly involved in this quantity, all experience points to the conclusion that it involves variable elements, and the hypothesis that it is a constant of one term, is not in accordance with the physical conditions of the problem, and that this formula requires correction for ignored and misrepresented elements.

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[1] See paper "on Steamship Efficiency," by Mr. Robert Mansel, *Trans. Inst. Engineers and Shipbuilders in Scotland*, vol. xxii.

Obviously, the formula may be written—

$$C\frac{E}{V} = M V^2 \qquad (1)$$

in which it is asserted, the true form of C in the first member is unknown, and the quantities represented by the factors M, and V^2 of the second, are, at best, but rudely approximate.

It has been stated by me that a better approximate form for the factor expressed by M in the Admiralty formula is the quantity $L\sqrt{M}$, that is to say, the product of the length of the vessel into the square root of the immerged midship section; only, to meet a correction necessitated by the known fact that when uninfluenced by restricted depth of water, small vessels experience greater proportional resistance than larger ones, and also corroborated by D'Arcy's exhaustive experiments on the flow of water, in which it was shown that the diameter of the pipe entered inversely as an element of the resistance. It was therefore proposed, as a practical but empirical correction, to take the ⅞th power of this quantity instead of its full value, and hence, on this hypothesis, the quantity *b* comes to be represented by the approximate value—

$$b = \frac{(L\sqrt{M})^{7/8}}{C}.$$

In which C is a constant involving a number of factors, and corresponds to, but is not the same as the C of the Admiralty formula, and thus we finally arrive at the following equation—

$$\frac{E}{V} = \frac{(L\sqrt{M})^{7/8}}{C} \log.^{-1} aV. \qquad (3)$$

The factor $\log.^{-1} aV$ of the second number being the notation by which is expressed, *the number whose common logarithm* is the product of a small quantity, *a*, into the speed, V knots.

The crucial practical test of the accuracy of the speed factor of the second member, is to apply the formula to the progressive speed trials of actual steam vessels. For, taking the common logarithms of both members, and with the speeds taken along an axis as abscissas, if we set up the values of the first number $\log. \frac{E}{V}$, as ordinates; these values will range in a straight line, inclined to the axis at an angle dependent upon the value of *a*, and having the ordinate at the origin equal to the value of the factor $\log. \frac{(L\sqrt{M})^{7/8}}{C}$, or, simply, $\log. b$; whence, by measurement and calculation, or calculation alone, it is easy to obtain the value of C, which will be found a constant quantity in all the experiments, *so long as the conditions of the trial are unchanged.* We thus completely remove the objectionable variations of coefficient of the Admiralty formula, which, in the same vessel and circumstances, usually gives a new value of C for every value of V.

To illustrate the constancy of the derived coefficient, in passing from vessel to vessel, let us make use of experimental data which, treated by the Admiralty formula, offer great variations; for example, to a few cases of paddle vessels with feathering floats, of which (except the *Paris*), having only one experiment, and consequently being unable to determine a, it is assumed that the value of this is ·0796. (Tabular results of experiments are given by the author.) The problem therefore is, having given the length and area, power and corresponding speed, of certain paddle vessels, to calculate from the formula,

$$C\,\frac{E}{V} = (L\sqrt{M})^{7/8}\ \log.^{-1}\ {\cdot}0796\ V,$$

the value of C the efficiency coefficient, and to contrast the same with the values yielded by the formula,

$$C\,\frac{E}{V} = M\,V^2.$$

Results of Calculation of Efficiency of the following Paddle Vessels.

Name.	Length.	Mid. Area.	Log. $(L\sqrt{M})^{\frac{7}{8}}$	Trial Power.	Corresponding Speed.	Efficiency Co-efficient.	Admiralty Co-efficient.
Shannon, ..	329	610	3·4212	2928	13·90	160·0	559·5
Paramatta,	329	606	3·4199	2940	13·95	160·9	560·0
Admiral, ..	211	214	3·0557	744	11·87	159·8	485·7
Paris, ...	219	177	3·0248	1030	13·41	161·0	400·4
Wolf, ...	239	220	3·1059	1500	14·19	159·2	391·1

It will be seen that the formula virtually embracing the whole is,

$$E = \frac{(L\sqrt{M})^{7/8}}{160{\cdot}4}\ V\ \log.^{-1}\ {\cdot}0796\ V.$$

The efficiency coefficient 160·4 giving as close a result as would be obtained by the use of three values of the Admiralty formula coefficient, say 560, 486, and 400. Having thus exhibited the range and accuracy of the proposed system of comparison with the ordinary run of merchant vessels, let us now apply them to the valuable data furnished by Mr. White, so as to compare results."

The author then proceeds to a comparison of various experimental results, and finds that the efficiency coefficient for vessels of H.M. navy and mercantile marine vary from about 80 to nearly 600, and points out that the conflicting elements which enter into this question, especially when dealing with screw steamers, still demand carefully made experiments for their solution.

Diameter of cylinder.—To find the diameter of the cylinder, the velocity of the piston in feet per minute must be determined, and it ranges from 300 feet for short strokes, to 600 feet and upwards for strokes of 4 feet 6 inches. The maker is generally allowed to fix the speed he considers best under the circumstances. To find the number of square inches per horse-power, divide the constant 33,000 by the product of the speed multiplied by 7, the result gives the square inches per horse-power; then multiply this by one-half of the nominal power required, and the result is the area of each cylinder in square inches. When great exactitude is required, add one-half of the area of the piston rod, or trunk, if adopted for single trunks, or the whole area for double trunks; this is necessary, as the trunks take up a large area in comparison to the piston rod. These combined areas in either case will give the true area of the cylinder in square inches, and by a table of areas, which the engineer should always have by him; the diameter of the cylinder is easily ascertained.

Stroke of piston.—For short strokes giving a large area of piston per horse-power, a good result will be obtained by dividing the diameter of the cylinder by 1·76. It is evident, however, that when high steam pressure is used, much longer strokes can be beneficially adopted; and by this means we can reduce the weight of the parts below what is required when the steam is admitted into the cylinder at a high rate of pressure, as in the combined high and low pressure cylinder arrangements, now extensively adopted.

Depth of piston and length of cylinder inside.—The depth of piston is usually one-fifth to one-sixth of the diameter of the cylinder, to which add the length of the stroke, making an allowance for clearance at the ends of ½ inch for small, to ¾ inch for large pistons, and the product is the length of the cylinder inside, or space occupied by the steam from the inside of the front end to the inside of the cover.

Steam and exhaust port in cylinder.—To obtain a free steam and exhaust, the ports in the cylinder are greatly in excess of the valve opening—one-nineteenth of the area of the cylinder for the steam port, and one-eighth for the exhaust port. The latter is ruled by the distance of the face of the valve from the centre of the cylinder; and as the exhaust into the condenser is greatly contracted in the passage at the side of the port, the exhaust port is made broad in the direction of the travel of the valve.

Length of ports for double-ported valves.—The steam ports in the cylinder are divided by a centre rib about 1½ inch broad, while the exhaust port is left free. The combined length of the steam ports is found by dividing the diameter of the cylinder by 1·7, to which add the breadth of the centre rib.

Steam way or opening by valve, lap, &c.—The full opening of the steam way by valve is found by multiplying the area of the cylinder in square inches by the speed of the piston in feet per minute, dividing the product by the constant 10,000; the result divided by 2 gives the openings for double-ported valves, or four openings formed with the central ribs. The width of the opening is of course determined by the length of the ports, and it is an all-important consideration, as it regulates the supply of the steam into the cylinder, and consequently the number of strokes or revolutions of the cranked shaft; and from it the correct lap of the valve is obtained for cutting off the steam at that part of the stroke which is arranged for giving the greatest indicated measure of power in conjunction with the steam pressure that is determined on. The lap of the valve depends on what part of the stroke of the piston the cut-off commences, and is explained at p. 122; the length depends on which class of valve is adopted. The length of doubled-ported valves is considerable, but the benefit of having a short stroke is obvious, as the eccentrics are not nearly so large, and all the minor details are correspondingly reduced. The length of the valve is simply the sum of the ports and bridges or bars on the cylinder face, to which must be added the two outside laps.

Steam pipe on valve casing and exhaust pipe.—The steam-pipe branch on the valve casing is about one-twentieth of the area of the cylinder; the main steam pipe is two-thirds of the two combined. The exhaust pipe into the condenser is one-twelfth of the area of the cylinder.

Relief valve for cylinder.—The diameter of the relief valve is found by dividing the diameter of the cylinder by 12. Smaller cocks are sometimes fitted on the same valve chest, and worked by levers, rods, and handles from the starting platform.

Thickness of cylinder.—For ordinary steam pressure ranging up to 30 lbs. per square inch in the boiler, the thickness of a cylinder 25 inches in diameter is ⅞ inch, and for every 5 inches of additional diameter add $\frac{1}{16}$ inch to the thickness. The flanges for the covers should be one-fourth more than the body; the ends and covers one-tenth more than the body. The ends and covers should be strongly ribbed with deep bars cast on, radiating from the centre; the depth of the covers, including ribs, should be about one-eighth of the diameter of the cylinder. For additional strength the body of the cylinder is cast with two or more deep rings, to which are secured the rings of wood fastened to the lagging with ordinary screw nails. A manhole is cast in the covers of large cylinders, fitted with a lid; and the hole for the boring bar on the end of the cylinder is of sufficient size to inspect the inside of the cylinder, and is also fitted with a cover which can be easily removed. The thickness of the sides of the steam chest varies from ¾ inch for small to 1¼ inch for large diameters, and is strongly bracketed where required. The steam ports are divided by a central rib, but the exhaust port is left free, so that the passage for the waste steam to the condenser is not interfered with. The exhaust is generally carried round the cylinder through a broad belt, but this depends entirely on the arrangement of the pipes leading into the condenser.

Double-ported valve.—The thickness of this valve for small sizes is ⅝ inch, ranging to 1¼ inch for larger sizes; and it is cast with a centre rib to strengthen it. The diameter of the annular space for receiving the metallic rings, for taking the pressure of the steam off the back of the valve, should be as large as convenient; the depth of the recess in the cover is found by multiplying the breadth of the rings by 2; the breadth of the rings ranges from 1½ to 1¾ inch, their thickness being about ⅝ inch for large sizes, to ¾ inch or more for extra sizes. The set screws are generally ¾ inch in diameter, fitted with jam nuts and washers. The valve casing is an open casting varying from ¾ to 1¼ inch in thickness; the flanges for bolting it to the cylinder, and for the cover, may be ¼ inch more than the thickness of the sides. The steam pipe is at one end, and the steam passage tapering to the extreme end.

Piston rod and stuffing box.—To find the diameter of the piston rod multiply the area of the piston by the full pressure in the boiler, to which add the vacuum or 12 lbs. per square inch, and divide the product by 2240; the quotient gives the area of the rod in square inches for compressive strain. For tensional strain where cotters are used, or where the piston is attached to the rod by a nut, divide by 4000, which gives the sectional area at the bottom of the thread.

No part of the piston rod, such as the sectional area at the part where cotters are used, should be made smaller, so that the rod may safely take the greatest tensional strain imparted by the full steam pressure plus the vacuum. When two piston rods are used for return connecting-rod engines, add one-fourth more area; this is necessary as the vibration of long rods is rather severe at the high rate of piston speed now adopted. The depth of the stuffing box, from inside of the cylinder end to the face of the flange, equals the diameter of the piston rod multiplied by 2; the breadth of the packing space equals the diameter of the rod divided by 4; and the thickness of the stuffing-box flange equals the rod divided by 3. When four or more bolts are used for tightening up the gland, their combined area is found by dividing the piston rod area by 6.

Slide-valve rod.—To find the sectional area of the slide-valve rod, multiply the full area of the valve by the full pressure, as for the piston rod (*i.e.* steam and vacuum), to which add the weight of the valve in lbs., and divide the result by 2240; one-sixth of the quotient equals the area of the valve rod in square inches at the weakest part. Sometimes two rods are adopted, passing over the shaft on the return principle; in such cases each rod is but little reduced from the single-rod arrangement. To prevent the rods bending or springing, guides are fitted at about the middle of their length.

Eccentric strap, rod, and link.—The dimensions of the bolts for the eccentric strap are found by multiplying the total area of the slide valve by the steam pressure, adding the weight of the valve in lbs. as for the slide-valve rod, and dividing the result by 4000; one-sixth of the quotient divided by 2 will give the area of each bolt at the bottom of the thread. Find from a table of areas the corresponding diameter, to which add the depth of the two threads, which will give the full diameter; this may be made a trifle more to enable the thread or screwed part of the bolt to pass easily through the hole in the strap. The sectional area of the gun metal strap where it is bolted together at the lugs should be three times the area of the bolt at the bottom of the thread, increasing in thickness all the way round; its breadth equals about twice the diameter of the bolt. The thickness of the snugs should be one-fourth more than the thickness of the strap at the lugs. The thickness of the eccentric ring equals one-eighth of the diameter of the shaft, and the metal round the boss for securing the eccentric to the shaft equals one-seventh of the diameter. The eccentrics are generally cast open, with a strengthening rib between the boss and the outside ring. The pins for the eccentric rods are the same diameter as the slide-valve rod. The rods are forked at the link end, with a T end for bolting to the gun-metal eccentric strap; they are made quite flat, the area at the smallest end equals the area of the slide-valve rod, and for every foot in length add about ½ inch to the breadth of the rod. The bolts for the T ends are the same diameter as those for the strap. The slotted link is generally adopted; the distance between the centres of the eccentric rods on the link equals three times the throw of the eccentric. The holes for receiving the pins are fitted with gun-metal bushes cast hard, and adjusted with set screws, screwed into the lugs on the link. The sectional area of the slide-block pin is found by multiplying the slide-valve rod area by 1·3. The pin is conical, and fitted with a tapered ferrule of steel, which is split, having set screws and nuts on pin for adjusting the wear. The slide block is of brass, with a loose side flange secured with screws; the length of the block equals twice the diameter of the pin. The width of the link should be about one-sixth more than the diameter of the slide rod; the sectional area equals that of the slide-block pin. The sliding block or crosshead to which the pin is secured is generally a flat bar, moving in brass guides, the crosshead having a lug forged on for taking the slide-valve rod. The point of suspension on the link is midway between the eccentric rod pins, on the radius line of the link, a cross bar and pin being rivetted to the link at that point. The suspension rods are found by dividing the valve-rod area by 1·6, which gives the area of the pin in square inches; their diameter at ends equals the diameter of the pin. The suspension rods have brass bushes fitted in the eyes.

Power required to move the slide valve.—The power required to move the slide valve depends on the size of the valve and amount of pressure on the back of it, to which is added the weight of the valve in lbs. One-sixth of the total may be considered the force in lbs. that is required to move the valve when under full pressure (*i.e.* steam and vacuum). In practice, for an area of 800 square inches of valve surface on the back of valve, and when provision is made with rings on the back to relieve the valve from the steam pressure, a power of 7 to 1 is allowed; with a steam pressure from 20 to 30 lbs. per square inch, supposing the valve's area was 4000 square inches, more of course would be needed, the area being five times as much, or a proportion of 35 to 1 would be required; that is to say, the starting wheel would require to make 35 revolutions for one of the shaft on which the lifting arm for raising and lowering the link is fitted. Of course for small power a valve should be arranged to take the steam pressure off the back, when the slide valve is moved by hand, thus lessening the labour in reversing the gear.

Connecting rod.—The thrust and pull on the connecting rod receive the full force exerted on the piston, and the same rule holds good as for the piston rod, namely, 2240 lbs. for compressive stress and 4000 for tensional strain. This gives the number of square inches of area for the ends of the rod, an allowance of one-fourth of an inch in diameter for every foot in length gives the diameter at the middle. The thickness of caps, when so fitted, is one-half of the diameter of the rod. The combined sectional area of the bolts at the bottom of the thread is found by dividing the total pressure on piston (*i.e.* steam and vacuum) by 4000. When straps are used, the combined area at the brasses and key-ways must equal the area of the rod at end. The breadth of jibs and cotters equals the diameter of the rod, and the thickness of the key is found by multiplying the diameter of rod by ·31; the thickness of brasses at ends is found by dividing the diameter of the crank pin by 8, and for the side one-half will suffice. The brasses are planed out and lined with white metal, the proportion being for large sizes 1¼ inch of brass surface all round with a mid strip left.

Main cranked shaft.—The same rule holds good as regards the diameter of a shaft with cranks forged on in one piece, and plain cranks shrunk on a straight shaft. When the cranks of two engines are placed at right angles to each other, the shaft should have the same area as a single engine having the same force exerted on the piston, the length of the crank from centre to centre being identical. To find the diameter of the shaft, multiply the length of the crank in inches by the total pressure on the piston (*i.e.* steam and vacuum), and divide the sum by 1206; the cube root of the quotient will be the diameter of the shaft. The collars at the bearings for large diameters may be 1 inch. The length of the two outside journals is generally equal to twice the diameter of the shaft at the journal. The middle bearing is made longer according to the distance between the frames for supporting the shaft. The crank pin is the same diameter as the journal; the distance between the jaws of the crank is found by multiplying the diameter of the journal by ·87; the thickness of the cranks in the line of the length of shaft is found by multiplying the diameter by ·8, and the breadth equals the diameter over the collars. All the collars should be made with a bold radius at the journals, for shafts generally give way at the sharp corners after long running.

Crosshead and guides.—The diameter of the crosshead for return connecting-rod engines is found by dividing the total pressure on the piston by 1400, the quotient is the area in square inches. The width of each block for taking the upward and downward thrust of the connecting rod equals the diameter of the crosshead, and the length is twice the diameter. The blocks are of brass or cast iron lined with white metal. The depth of the top motion bars or guides equals three-fourths of the diameter of the crosshead. Some engineers allow clearance between the blocks and guides at the top, depending on the weight of the crosshead and adjuncts to neutralize the thrust; one-eighth of the total pressure on the piston can be safely taken for calculating the bolts; the motion bar being taken as a beam loaded at the middle, having a section of an I form, or centre rib, with flanges at the top and bottom. Of course the thrust varies according to the angle of inclination; it is less with a long than with a short rod. From four and a half to five times the radius of the crank, or the length from the centre of the shaft to the centre of the crank pin, is about the average length for the connecting rod.

Main frame.—The main framing is subjected to direct tensional and compressive strains, and to a certain extent also to twisting stress. As the cohesive strength of cast iron is less than that of wrought iron in the ratio of one of wrought iron to three of cast iron, the combined sectional area of the framing should not be less than three times the area of the piston rods; but when we consider that the framing forms the backbone of the structure, and may be subjected to tensional, compressive, and twisting strain at one and the same time, more area is required. When of an I section, the centre web varies from ⅞ inch for small to 1¾ and 2 inches for heavy engines; the flanges for bolting down to the keelson, cylinder, and condenser, one-fourth more than the centre web; and all the other flanges one-eighth less than the centre web. The breadth of frame equals the diameter of the shaft at the journals. The depth of the top limb for bolting to the cylinder equals the diameter of the shaft, and that of the bottom one at the cylinder is one-fourth less in depth; the limb for bolting to the condenser may be made a little more than one-half of the diameter of the shaft. The various forms of framing have been already noticed. The thickness of the brasses at the bottom is one-seventh of the diameter of the journal. The caps when of wrought iron are one-third of the diameter of the journal, and when of cast iron one-half. The combined area of the cap bolts is found by multiplying the combined area of the cylinders by the total pressure of the piston, as for the piston rods, &c., dividing the result by 4000. The brasses are recessed about ¼ inch in depth, and filled in with white metal, the brass surface being about 1½ inch all round for large shafts, with a bottom strip running lengthways.

Piston.—The piston has generally a depth of from one-fifth to one-sixth of the diameter of the cylinder. The packing ring should not be less than one-ninth of the diameter of the cylinder; its greatest thickness one-fifth of its breadth, diminishing to the part where it is cut through. The rubbing surfaces of the junk and bottom rings can be made of about the same collective breadth as the packing ring, with projections formed on the junk ring and bottom of piston projecting from their respective thicknesses; this tends to make the wear of the spring ring and piston more equal. The ends of the piston may be somewhat less in thickness than the cylinder; they are strongly ribbed, and have all the necessary bosses cast for the piston rods. The bolts for the junk ring vary from ¾ to 1¼ inch in diameter, according to the size; in some cases they are merely tapped into the cast iron, in others nuts are inserted in the body of the piston. The spring ring is kept up to the cylinder face with flat or U-shaped springs, recessed into the body of the piston. Two pieces of cast iron are inserted between the packing ring and the piston, which serve to keep the body and packing ring central with each other; the pitch of these blocks is about one-fifth of the circumference of the ring inside. (See p. 403.)

Air pump, condenser, &c.—The capacity of the air pump equals one-eleventh part of the cubic contents of the cylinder for double action, and double of that quantity for single action; the length of the stroke being the same as for the steam cylinder. Thus the area of the cylinder is divided by 11 or 5·5, as the case may be, to obtain the area of the air pump. The lining of the air pump varies from ½ to ¾ inch in thickness. The depth of the air pump piston equals one-fourth of the diameter of the pump; the diameter of the air-pump rod equals the diameter of the pump divided by 7. The area of the foot-valve passages in the condenser equals the full area of the pump, but for the head-valve passages more is allowed, which is found by multiplying the area of the pump by 1·35; this result is only for one end. The area through the gratings for the foot valves should not be less than the pump area multiplied by ·61, and for the head valves ·83 is the multiplier. Of course more area in the passages and gratings may be allowed, as a large area reduces the lift of the valves, and renders the wear and tear of the india rubber less severe. The valve seats are secured to the condenser by ¾-inch stud bolts and nuts of Muntz metal. The capacity of the condenser is generally about 1·3 times that of the capacity of one cylinder, when a condenser is fitted to each, placed side by side. When the condenser is on the opposite side in relation to the cranked shaft, the capacity can be reduced, as the eduction pipe then forms a part of the condenser, and increases the total cubical contents. The area of the main discharge pipe equals the area of the air pump, or one-half the area for each. The thickness of the condenser varies from ¾ to 1¼ inch; all the flat surfaces should be strengthened with ribs in the casting. There should be an air vessel formed in the casting, placed above the head valves, so as to lessen the shock of the ejected water. The diameter of the snifting valve varies from 2½ to 4 inches, and it should be placed as low down as possible, so that all the air, water, &c., may be ejected in the act of blowing through.

Injection valve, &c.—To find the area of the injection pipe, multiply the cubic contents of the cylinder in feet by ·4, which gives the area in square inches for each condenser; the bilge injection may be less than this. The former should be placed as high up and the latter as low down as possible in the condenser.

Surface condensation.—The surface of the tubes, according to Hall, should have about 2800 square inches for the condensation of 60,000 cubic inches per minute, the quantity of cold water required being about 10 gallons. Some makers give about the same sq. feet of condensing surface as there are sq. feet of heating surface in the boilers (see p. 432). Of course, the pressure of the steam as it enters the condenser is the point to study in considering the amount of surface required; a very general rule is to multiply the total heating surface in the boiler by ·75, which gives the number of sq. feet of condensing surface. The air pump for the surface system may be less than for the injection system, ranging from one-twelfth to one-fifteenth of the cubical contents of the cylinder; it is, however, often made of the same capacity as the injection system, in the event of that system being adopted, in case of accident to the surface condenser.

Feed pump.—The number of cubic inches of water required for the boilers varies of course according to the evaporation of water in the boilers. To find the water required, multiply the cubic contents in feet of steam for one cylinder for an entire revolution by the cubic inches of water required for the steam used, that is the quantity required to be boiled off, and the result will give the cubical contents of the feed pump of the single-acting type. This result is only for one cylinder, and generally double the contents is allowed, so that in the event of one of the pumps getting out of order the other one will be able to keep up the supply. The area of the water passages in the grating, if india rubber valves are used, is found by the same rule as for the air pumps; for brass valves, divide the pump's diameter by 1·3, which gives the diameter of the valve. For the sake of uniformity, the bilge pump is the same size as the feed pump.

Screw propeller.—The screw's disc, or the circle represented by the diameter of the screw, should have an area of about 1 foot for every 2·75 square feet of midship area or immersed section; while the actual area of the blades may be put down at about 1 square foot for every 7 to 10 square feet in the midship section. The thickness of the roots of the blades for cast iron is found by multiplying the diameter of the screw by ·55, this tapering to 1¼ inch at the point on the average. When the screw is made of gun-metal multiply the diameter by ·44, which gives the thickness at the root, and all the other parts in proportion. To find the pitch of the screw, multiply 6080, the lineal feet in a knot or nautical mile, by the speed in knots per hour that is required, dividing the result by the number of revolutions of the screw multiplied by 60 minutes, and the quotient will give the pitch of the screw as it were working in a solid nut. A certain amount, however, must be allowed for slip. Deduct that amount from 100, which we will name the *divisor*, then multiply the pitch as already found by 100, and divide that quantity by the divisor: hence the formula—

$$100 - \text{slip} : \text{pitch as found} :: 100 : \text{actual pitch}.$$

TABLE OF THE PROPORTIONS OF GRIFFITH'S SCREW PROPELLER.

Diameter of Screw.	Diameter of Boss.		Length of Boss.		Diameter of Flange of Blade.		Thickness of Flange of Blade.	Diameter of Shank of Blade.	Metal round Shank.	Metal between Flange and top of Cutter.	Width of Main Cutter.	Thickness of Cutter.	Widest part of Blade above Boss.	Width of Blade at widest part.		Width at Point of Blade.		Thickness at Root.	Thickness at Point of Blade.	Thickness of Feather in Boss.	Angles on Sides of Wedge Box.
ft.	ft.	in.	ft.	in.	ft.	in.	in.	in.	in.	in.	in.	in.	in.	ft.	in.	ft.	in.	in.	in.	in.	degrees.
6	1	9	1	1⅜	0	10½	½	5¼	⅞	1¼	2⅝	⅞	4½	2	0	0	10½	2	5/16	½	7½
7	2	0	1	3	1	0	⅝	6	1	1¾	3	1	5¼	2	4	1	0	2 5/16	⅜	⅝	,,
8	2	3	1	4⅞	1	1½	11/16	6¾	1⅛	1⅞ 1/16	3⅜	1⅛	6	2	8	1	1¾	2⅝	7/16	11/16	,,
9	2	6	1	6¾	1	3	¾	7½	1¼	2 3/16	3¾	1¼	6¾	3	0	1	3⅜	3	½	¾	,,
10	2	9	1	8⅝	1	4½	¾ 1/16	8¼	1⅜	2⅜	4⅛	1⅜	7½	3	4	1	5⅛	3¼	½ 1/16	¾ 1/16	,,
11	3	0	1	10½	1	6	⅞	9	1½	2⅝	4½	1½	8¼	3	8	1	7	3⅝	⅝	⅞	,,
12	3	6	2	2¼	1	9	1 1/16	10½	1¾	3 1/16	5¼	1¾	9	4	0	1	8½	4	⅝ 1/16	1 1/16	,,
13	3	6	2	2¼	1	9	1 1/16	10½	1¾	3 1/16	5¼	1¾	9¾	4	4	1	10¼	4¼	¾	1 1/16	,,
14	4	0	2	6	2	0	1 3/16	12	2	3½	6	2	10½	4	8	2	0	4⅝	¾ 1/16	1 3/16	,,
15	4	0	2	6	2	0	1 3/16	12	2	3½	6	2	11¼	5	0	2	1¾	5	⅞	1 3/16	,,
16	4	3	2	7⅞	2	1½	1¼	12¼	2⅛	3⅝ 1/16	6⅜	2⅛	12	5	4	2	3⅜	5¼	⅞ 1/16	1¼	,,
17	4	6	2	9¾	2	3	1⅜	13½	2¼	3⅞ 1/16	6¾	2¼	12¾	5	8	2	5⅛	5⅝	⅞ 1/16	1⅜	,,
18	5	0	3	0½	2	6	1½	15	2½	4⅜	7½	2½	13½	6	0	2	6⅛	6	1	1½	,,
19	5	0	3	0½	2	6	1½	15	2½	4⅝	7½	2½	14¼	6	4	2	8½	6¼	1 1/16	1½	,,
20	5	6	3	5⅛	2	9	1⅝	16¼	2¾	4¾	8⅛	2¾	15¾	6	8	2	10¼	6⅝	1 1/16	1⅝	,,
21	5	6	3	5⅛	2	9	1⅝	16¼	2¾	4¾	8⅛	2¾ 1/16	15¾	7	0	3	0	7	1⅛	1⅝	,,
22	6	0	3	9	3	0	1¾	18	3	5¼	9	3	16½	7	4	3	1¾	7¼	1 3/16	1¾ 1/16	,,
23	6	0	3	9	3	0	1¾ 1/16	18	3	5¼	9	3	17¼	7	8	3	3⅜	7⅝	1 5/16	1¾ 1/16	,,
24	6	6	4	0⅝	3	3	1⅞ 1/16	19¼	3¼	5⅝	9⅝	3 5/16	18	8	0	3	5⅛	8	1⅜	1⅞ 1/16	,,

Blades of screw to curve forward half an inch to every foot diameter of screw from face to root; curve in blade to commence at centre of blade.

Screw aperture.—The length of the screw aperture for a merchant ship depends in a great measure on the configuration of the screw propeller. Dividing the diameter of the screw by 2·5 gives ample room for the generality of propellers at present in use.

Screw shafting and thrust collars, pillow blocks, &c.—The propeller shaft should have the same diameter as the cranked shaft. The taper of the part for the screw boss should be about 1¼ inch for every 2 feet in length, the mode of fastening being a nut on the end, with feather let into the shaft and boss. To find the area and diameter of the lying shafting, divide the area of the cranked shaft at the journals by 1·13, the quotient gives the area in square inches; and by a table of areas the diameter is easily found, always allowing over rather than under, and even dimensions being preferred. The thickness of the solid discs forged on the shaft is about one-third the diameter of the shaft. A projection of ¾ inch, and about five-eighths of the diameter of the rest of the shaft, is left on, and accurately fits into a recess bored out in the adjoining shaft, keeping the shafts central the one with the other; the combined area of the bolts for the coupling is found by multiplying the area of the shaft by ·35. A key is sometimes sunk into one of the discs and secured with screws, one-half of the key taking each disc; thus the shearing strain is taken off the bolts, which can therefore be greatly reduced in area. The thrust of the screw is received on a series of collars accurately turned on the shaft. The combined area of the thrust surface is found by multiplying the nominal horse-power of the engine by 1·25, which gives the number of square inches of surface in the whole series of collars, the length and depth of the collars being one-eighth of the diameter of the shaft. The length of the pillow blocks for the lying shaft is one and a half times the diameter of the shaft. The length of the plate for the thrust block is about six times the diameter of the shaft; it is well joggled at the ends to prevent lateral movement.

Hand gear.—The rods must either be unnecessarily large in diameter, or supported at the middle; the required strength very rarely exceeds 1 inch in diameter. The joint pin is of the same diameter as the ends of the rod, the diameter of the eye equals the diameter of the pin multiplied by 2, and the depth of the eye equals the diameter of the pin. This rule is for single joints, which should always be used when convenient, because they are more easily made; when double joints are used, the distance between the jaw of the joint equals the pin's diameter, while one-half of the diameter equals the thickness at the smallest part. Sometimes hollow rods are adopted with advantage.

Bolts in cylinder cover.—The bolts vary in size from ⅝ to 1¼ inch in diameter; the pitch from centre to centre of the holes is generally about eight diameters. To find the combined area of the bolts, multiply the area of the cylinder by the steam pressure, divide the product by 2240, and then by the number of bolts required, which gives the area of each bolt at the bottom of the thread; adding the depth of the threads will give the full diameter of the bolt.

Turning gear.—The arrangement is generally a worm, working in a wheel fitted to the end of the cranked shaft, the diameter of the wheel being about 3¾ times the radius of the main crank, the pitch of the teeth being 2½ inches. The diameter of the worm equals one-sixth of the diameter of the wheel.

Safety valve, waste-steam pipe, &c.—For every square foot of fire-grate surface, allow ·5 of a square inch, this multiplied by the nominal horse-power gives the total area of the valves; then dividing by the number of boilers gives the area of one valve for each. Two safety valves are, however, better than one; and it would appear that one-half of the area is required for each, but the practice is to give two valves of the combined circumference of the large one, on the ground that no more steam can escape with a certain lift than the circumference of the valve will admit of. If there were four boilers, of course there would be eight valves: the main waste-steam pipe for these will be eight times the area of one valve, or the combined area of all the valves; while the branch pipes will be reduced in size according to the arrangement of the valve chests. (See "Report on Safety Valves," at p. 462.)

Copper steam pipes.—The steam pipes, blow-off, bilge, and waste-water pipes, as used in the royal navy, are not less than ¼ inch in thickness; feed and injection pipes $\frac{3}{16}$ inch, and waste-steam pipes ⅛ inch in thickness. The diameters of the pipes depends on the arrangement of the boilers, &c.: when four boilers are used, for instance, the stop valves and branch pipes are one-fourth of the area of the main steam pipe. The blow-off pipes are generally about 3 inches in diameter. The main feed pipe should equal the diameter of the feed pump, when plungers are used of the same stroke as the steam piston; but when the pump is situated a long way from the boilers, more may be adopted. The branch pipe and non-return valve on the boiler is generally about 2½ inches in diameter.

Kingston valves, blow-off and injection cocks.—The following table gives the number and diameters generally adopted, but of course these are regulated entirely by the arrangement of the piping:—

Horse-power.	Kingston.		Blow-off Stop Cocks.		Kingston.		Injection Stop Cocks.	
	No.	inches.	No.	inches.	No.	inches.	No.	inches.
60	1	3½	2	3	1	5	2	3½
80	1	3	2	3	1	5	2	3½
100	1	4	1	4	1	4	1	4
150	1	3½	1	3	1	3½	2	3½
200	2	4	2	4	2	4	2	4
300	2	4	4	3	2	5	2	5

Flanges for copper pipes.—

Diameter of pipe in inches		Diameter of flange in inches.	Diameter of pipe in inches		Diameter of flange in inches.
1½	=	4	7½	=	11
2	=	5	8	=	11½
2½	=	5½	8½	=	12
3	=	6	9	=	12¾
3½	=	6¾	9½	=	13¼
4	=	7½	10	=	13¾
4½	=	8	10½	=	14¼
5	=	8½	11	=	14¾
5½	=	9	11½	=	15¼
6	=	9½	12	=	15¾
6½	=	10	12½	=	16⅜
7	=	10½	13	=	17

Sometimes for large diameters a raised ring is cast along with the flange for bolting the pipes together, to which the copper pipe may be securely rivetted; in other cases they are simply brazed on, having a raised bead left on the flange to give a better hold.

LOCOMOTIVE ENGINES.

In this form of the steam engine, which has now advanced to a high degree of perfection, the agency of steam is employed in the simplest form in which it is capable of producing power, namely, by the mere excess of its pressure above that of the atmosphere. The reason why the more economical process of condensation is inapplicable in this case is obviously the increase of weight and complexity attending the use of that process, both of which should be avoided as much as possible in a machine which propels its own weight at an immense velocity over a road composed of yielding materials, all more or less liable to wear and tear from the effects of momentum and friction. The qualifications for a perfect locomotive are not easily reconcilable with each other, and demand the utmost skill, combined with long experience, on the part of the maker.

We have said that lightness and simplicity of parts are desirable; but these, on the other hand, must not interfere with the safety and the economical working of the engine. Its stability must be insured by the position of the wheels and the centre of gravity; and every available means must be adopted for increasing, first, the evaporative power of the boiler, and secondly, the mechanical effect of the steam, without unduly increasing the weight and cost of the apparatus. It is evident that any increase in the economical working of the locomotive effects a twofold saving, namely, in the cost of the fuel and in the weight to be carried. Hence the steam is worked at a very high pressure (about 150 lbs. above the atmosphere), and is cut off and expanded in the cylinder.

It is well understood that railways owe their origin to the necessities of the trade in coal, and that the improvement of the engine followed gradually upon the improvement on the road on which it was constructed to run. Among the names most conspicuous for the introduction and improvement of the locomotive engine stand those of James Watt and his assistant William Murdoch, Richard Trevethick, Mr. Blenkinsop of Leeds, the brothers Chapman, Timothy Hackworth, and George Stephenson.

Under this section we shall first treat of the Locomotive proper and its Tender, as used on railways; and then notice various forms of Engines used for traction or haulage of machinery and road traffic, Portable Engines employed for driving agricultural machinery, Steam Rollers for roads, &c.

COMBUSTION IN THE LOCOMOTIVE.

THE STEAM BLAST—FIRE-BOX AND COMBUSTION CHAMBER.

The successful development of the locomotive engine has been mainly due to the introduction of the steam blast, or an application of part of the motive power for effecting a rapid and intense combustion of the fuel in the fire box of the boiler. This is produced by blowing the waste steam from the cylinders into the chimney, thus causing a partial vacuum, which is filled up by the air rushing through the fire box, carrying the flame and heated gases through the small tubes placed in the body of the boiler. By this means the water is exposed to a number of highly-heated surfaces; the thinness of these tubes adding greatly to their effectiveness in producing steam. The fire box, however, is undoubtedly that part of the boiler where the water is boiled more quickly, more especially at the top. This is due to the material of which it is composed—namely, copper—being a very good conductor, keeping quite free from incrustation, and the concentrated and intense vertical heat, caused by a due admixture of the oxygen of the atmosphere, forced in a measure amongst the live fuel. The practical limit to be arrived at is, that the blast must not be too powerful, so as to lift and carry off the fuel through the tubes, and then up the chimney

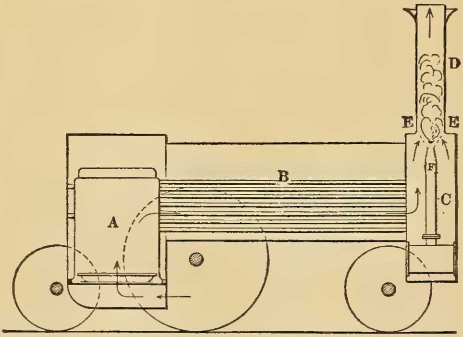


Fig. 379.—Diagram showing the Mechanical Action of the Blast.

A, Fire box. B, Tubes. C, Smoke box. D, Chimney. EE, Sides of chimney. F, Blast pipe.

to waste—the power of the blast that is required depending greatly on the quality of the fuel.

The mechanical action of the blast is very simple. The waste steam from the cylinders is led into a pipe concentric with the chimney. The end of the pipe should be quite straight, so that the expanding steam may strike equally on the sides of the chimney, as at E E; and it is of the greatest importance that the pipe should be placed exactly in the centre of the chimney. It is evident that when the steam is led through bent pipes, placed on each side of the smoke box, that the blast is imperfect, owing to the steam striking alternately on the sides of the chimney. So it becomes imperative that the blast pipe should be made quite straight at the end; thus the expanding steam strikes equally all round the chimney, producing a much better result. The blast pipe should taper from the under side upwards, and should be suddenly contracted at the orifice. Sometimes various sizes of nozzle or top pieces are provided; they are generally made of copper, and secured to the cast-iron pipe with a set screw. It is likewise preferable to braze a ring of brass on the top, and turn it out correctly to size, thus providing a smooth and accurate aperture for the escape of the steam.

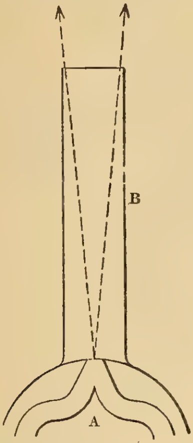


Fig. 380.—Disadvantage of Bent Blast Pipes.
A, Blast pipes. B, Chimney.

When the engine is not in motion a separate plug valve is used, which is fitted inside of the chimney with a pipe connection, communicating with the boiler. By this means the fire can be urged by simply blowing steam up the chimney directly from the boiler, independently of the blast pipe. Of course this separate valve is only used as a means of creating a circuit when the engine is not in motion, or in the act of raising steam quickly when the fire is kindled, a few pounds of steam pressure in the boiler being necessary, which is not considered as wasted when used for this purpose.

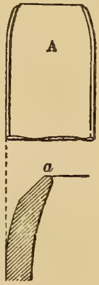


Fig. 381.—Form of Blast Orifice.
A, Blast orifice. a, Enlarged view

In order to still further increase the combustion of the fuel in the fire box when the engine is in motion, various mechanical contrivances have been tried, and none with better results than independent steam jets fitted to the fire box, forcibly inducting air by steam pressure amongst the incandescent fuel. With this object in view, the front and back or sides of the fire box are fitted with a row of tubes, placed at a convenient height above the fire bars. A steam pipe is fitted at the front, side, and back of the fire box, having a nozzle connected with each hollow stay or tube, the apertures being $\frac{1}{16}$ inch in diameter. A vertical pipe is fitted to this steam pipe, running to the top of the outside of the fire box, having a plug tap for regulating the supply of the steam. It has been proved by experiment that this contrivance greatly prevents smoke nuisance when coal alone is used, and effects a material saving in fuel. A much simpler plan, however, has been successfully adopted in coal-burning engines fitted with the ordinary fire box: it consists of a plate, easily removed, fitted to the aperture or fire door, and which is inclined downwards. By this means the current of air entering by the fire-door aperture passes downwards, instead of taking the direct course through the tubes,—thus meeting the flame and heated gases, and providing the necessary oxygen to effect complete combustion.

The ordinary fire box of the locomotive-engine boiler has been modified in various ways to effect a thorough combustion of the fuel, and likewise to prevent smoke nuisance when coal is used. All of the following schemes depend more or less on a free admission of air, with or without the use of a separate combustion chamber, in connection with the ordinary fire box. In land-engine boilers the air is admitted beyond the fuel, through apertures formed in the bridge at the back of the fire bars. Mostly all the mechanical contrivances introduced in the locomotive boiler aim at attaining the above objects by similar methods, namely, dividing the fire box by means of water spaces, formed of the same material as the fire box, to which latter air is admitted as in the ordinary land boiler.

The first example we will notice has two sets of fire bars laid at an inclination, having over them a hanging bridge, provided with an air pipe at the top. This plan was introduced for burning coal in combination with coke; the large grate was for the coal, and the small one, or fore grate, for the coke. Coal alone was charged on the hind grate, and coke on the fore grate, the design being to deflect the flame and heated gases by the hanging bridge over the incandescent coke, thereby consuming the smoke and gases. By the arrangement of inclined bars the coal gravitated, or was more easily pushed forward, to make room for fresh charges. This is quite correct in principle, as the dead coal should always be pushed gradually forward, and when this is properly attended to, smoke is greatly prevented in all furnaces. The proportion of fuel used on the Liverpool and Manchester Railway was two-thirds coal and one-third coke.

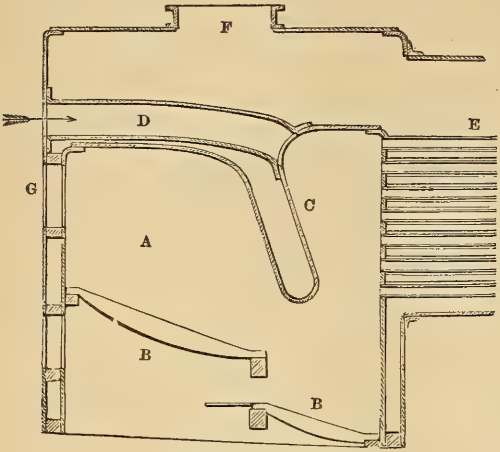


Fig. 382.—Combined Coke and Coal Fire Box, tried on the Liverpool and Manchester Railway.

A, Fire box. B B, Fire bars. C, Hanging bridge. D, Air pipe. E, Body of boiler, showing tubes. F, Manhole. G, Furnace door.

Another example on the same railway has been tried, giving favourable results, the fire box being arranged for burning coal. In connection with the ordinary fire box a second combustion chamber was introduced, which was divided from the fire box by a vertical water partition, containing a number of short tubes for the passage of the flame and gases. Air was admitted into the combustion chamber through vertical perforated pipes carried up from the bottom. A deflecting plate was likewise fitted to the combustion chamber,

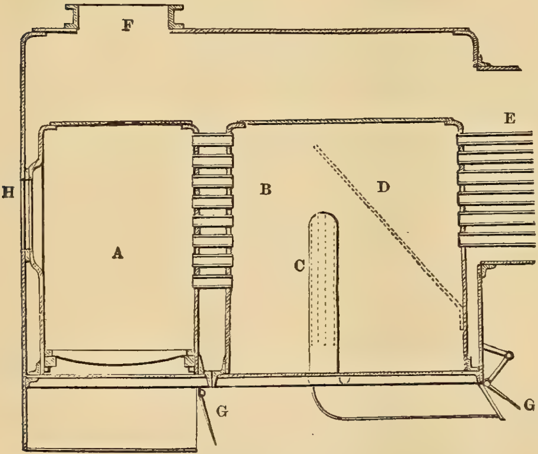


Fig. 383.—Fire Box, arranged for Coal Burning, with Combustion Chamber. Liverpool and Manchester Railway.

A, Fire box. B, Combustion chamber. C, Perforated pipe. D, Deflecting plate. E, Body of boiler, showing tubes. F, Manhole. G G, Dampers. H, Furnace door.

thus delaying, as it were, the passage of the gases through the tubes in the body of the boiler, and which we believe gave very favourable results. Of course it is essential that the bottom of the combustion chamber should be perfectly air tight, means being adopted for regulating the supply of air into the chamber up the vertical tubes.

Various other arrangements were tried on different railways, amongst these step grates, designed so as to admit a plentiful supply of air through the grate (Fig. 384). When the bars are stepped, or laid on an inclination, the fireman arranges the fire so that the live coal is always at the foot of the incline, while the dead or fresh fuel is at the top, near the fire door; thus the gases evolved pass over the incandescent fuel, and with a due admixture of air are more readily consumed. This plan works very well with free open coal, but with bituminous coal clinker forms, stopping up the space between the fire bars, and consequently burns them very soon. In some arrangements of step grates a movable grate is placed at the foot of the stepped bars, which can be readily opened for the removal of clinker and ashes.

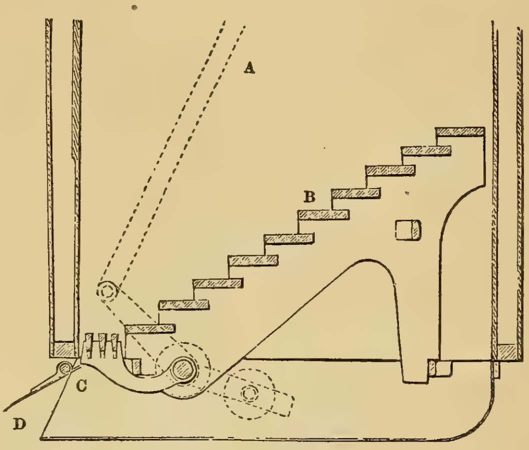


Fig. 384.—Step Grate.

A, Fire box. B, Step grate. C, Movable grate with lever and balance weight. D, Damper.

Another plan (Fig. 385) was tried, providing a much larger area of fire grate, burning the fuel more slowly, and giving a plentiful supply of air through the grate, and through hollow stays on the front and sides of the fire box, the fire box being divided up the middle by a water space, and carried inside of the barrel of the boiler to a considerable extent. By this means a large top surface was obtained, with the advantage of having a combustion chamber at the back, common to both furnaces. This plan, by careful alternate firing, no doubt tended greatly to consume the smoke of itself. A curtain plate has in some instances been added with

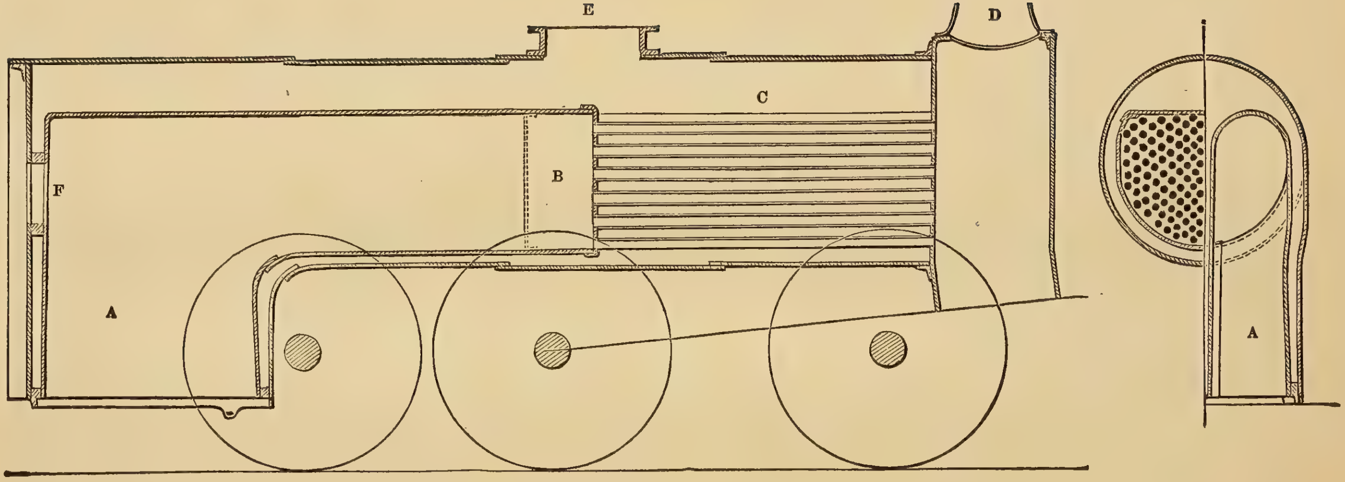


Fig. 385.—Long Fire Box. Longitudinal and Transverse Sections.

A, Fire box. B, Combustion chamber. C, Tubes in the body of boiler. D, Smoke box and chimney. E, Manhole. F, Furnace door.

advantage, which receives the full charge of air from the open doorway, the air being distributed through a number of small holes in the front of the curtain plate.

Other methods have been tried to effect complete combustion. One method (Fig. 386) consists of a small fire box placed at the back of an ordinary fire box; this plan is introduced for burning coal and coke, the latter being placed in the large fire box. The coal being consumed in the auxiliary fire box, the smoke and gases evolved pass through small short tubes into the main fire box, and are caused to make an upward direction through the interposition of a fire tile, thus passing over the entire length of the incandescent fuel in the main box before entering the small tubes in the body of the boiler.

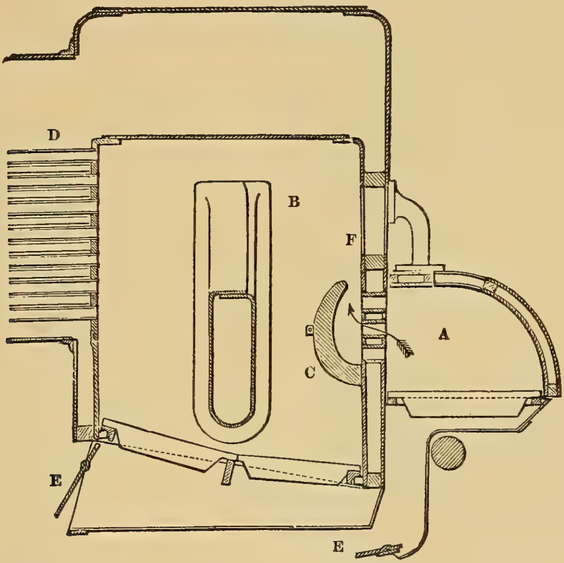


Fig. 386.—Auxiliary Fire Box. A, Small fire box. B, Fire box. C, Fire tile. D, Body of boiler showing tubes. E E, Dampers. F, Furnace door.

Another method was designed to burn coal alone. The fire grate, as in a previous example, is large, and is divided by an inclined water space into two compartments, having a separate door, fire grate, ash pan, and damper for each; the largest grate being at the back, near the foot plate. The flame and gases from this fire box rise, and, being met by a fine current of air entering

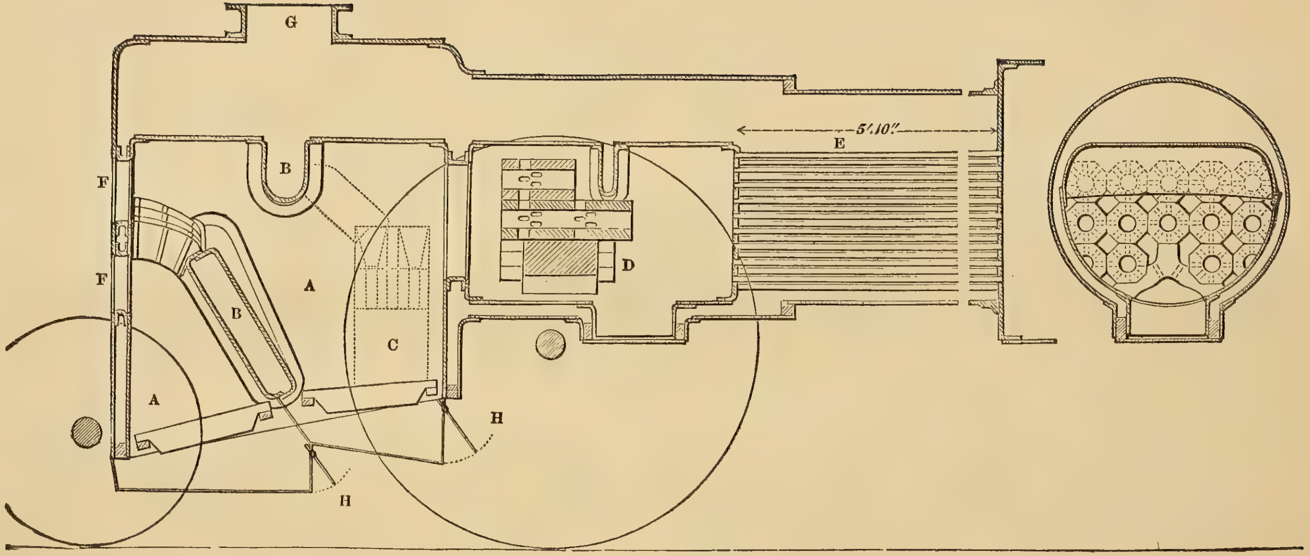


Fig. 387.—Fire Box and Combustion Chamber, fitted with Fire-brick Tiles. Longitudinal and Transverse Sections.
A A, Fire boxes. B B, Water spaces. C, Arch of brickwork. D, Combustion chamber. E, Tubes. F F, Furnace doors. G, Manhole. H H, Dampers.

the perforated fire door, pass through a perforated arch of brickwork into the front chamber. In the second grate the coal is burned slowly, the combustion being regulated by a careful admission of air through the damper. This arrangement also includes a second combustion chamber fitted inside of the body of the boiler, in which are placed perforated fire bricks at a convenient distance from the tubes in the body of the boiler. These fire-brick tiles receive and retain a portion of the heat when the fire is quite clear, and give off a portion of the retained heat when the fire is green, thus acting as equalizers of temperature. In some instances the combustion chambers have no fire bricks placed inside, the flame and gases from the fire box simply passing through short tubes forming the division between the fire box and combustion chamber, the latter being divided by a vertical water space. A door is fitted underneath the combustion chamber for cleaning and repairs.

Inclined bars have also been used, in combination with a curved diaphragm plate, fitted with tubes and a transverse water tube, the latter deflecting the flame and gases (Fig. 388). The gases having free passage through the tubes in the diaphragm, mix with the fresh air admitted. This plan does not seem to have met the

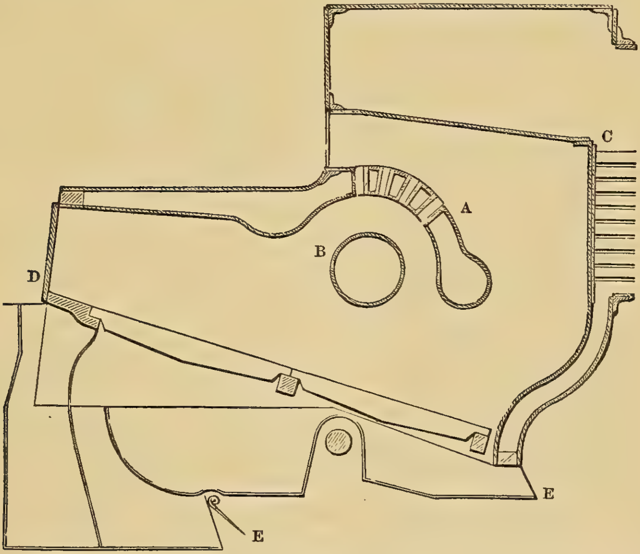


Fig. 388.—Inclined Fire Grate. A, Curved diaphragm in the fire box. B, Water tube. C, Tubes in the body of boiler. D, Furnace door. E E, Dampers.

designer's wish, owing, we have no doubt, to the excessive cooling surface, and the restriction and obstruction of the top of the main fire box, where the vertical heat is most beneficially utilized in the production of steam.

Another example of inclined bars, which differs materially from the foregoing, and which has been successfully carried out, may be noted. The fire box is divided by a longitudinal water space forming two separate fire boxes, uniting in one at the tube plate (Fig. 389). By this means the fires can be worked alternately, that is to say, when the one fire is bright the other is provided with fresh fuel, which slides forward on the incandescent fuel. The smoke and gases passing over the bright flame, and likewise meeting the flame from the adjacent furnace, are by this means effectually consumed; and it will be seen that the top surface of the fire box is better adapted for the production of steam than that of the foregoing example. There is a fire-brick lump introduced at the bottom of the inclined bars, which acts as an equalizer by giving off its heat during the act of firing, and adds to the efficiency of the boiler. Indeed, many examples of boilers of all descriptions have been found to be greatly improved by the introduction of these fire bricks.

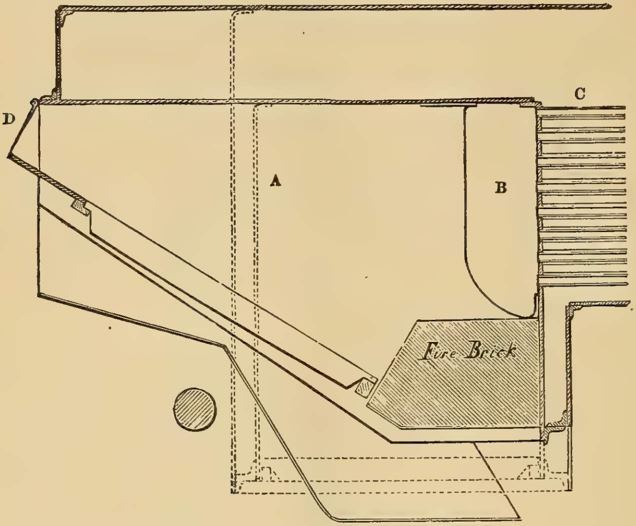


Fig. 389.—Inclined Grate, with Long Run. A, Fire box. B, Combustion chamber. C, Tubes in the body of boiler. D, Furnace door.

In another arrangement, with the view of giving greater length to the run of the flame in the fire box, a transverse water partition, and in some instances a fire-brick arch, was introduced, secured to the tube plate below the tubes, and inclining upwards towards the furnace door (Fig. 390). By this means the flame and gases are retained for a longer period in the fire box; and to assist combustion air is admitted through stay tubes in the front of the fire box, as well as through small holes in the fire door.

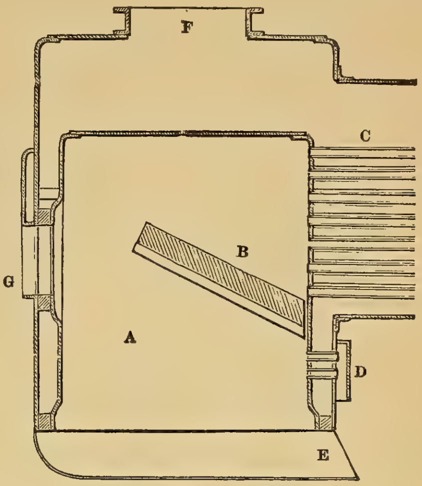


Fig. 390.—Fire Box fitted with Transverse Partition.

A, Fire box. B, Fire-brick arch. C, Tubes in the body of boiler. D, Air stay tubes. E, Damper. F, Manhole. G, Furnace door.

Another plan having the same object in view has been tried, in which the main difference consists in the fire-brick arch being made shorter than in the previous example. Some consider this an advantage, as the vertical

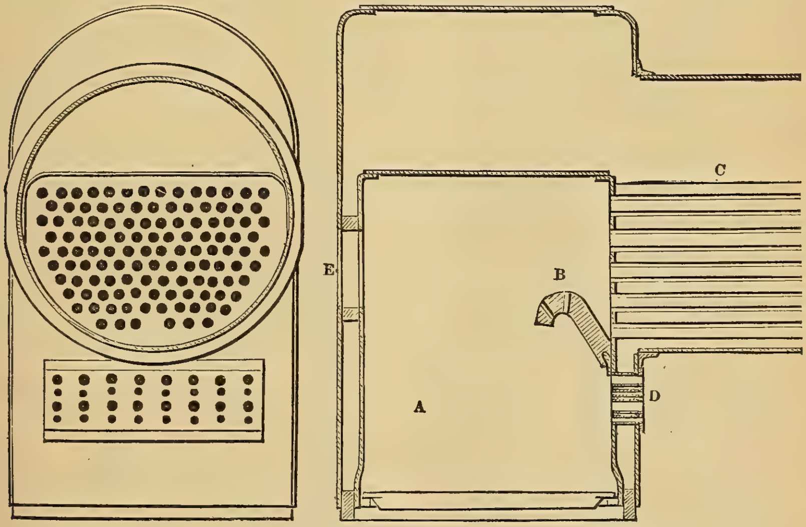


Fig. 391.—Tubular Stays, with Slide. Transverse and Longitudinal Sections.

A, Fire box. B, Fire-brick arch. C, Tubes in the body of boiler. D, Air stay tubes. E, Furnace door.

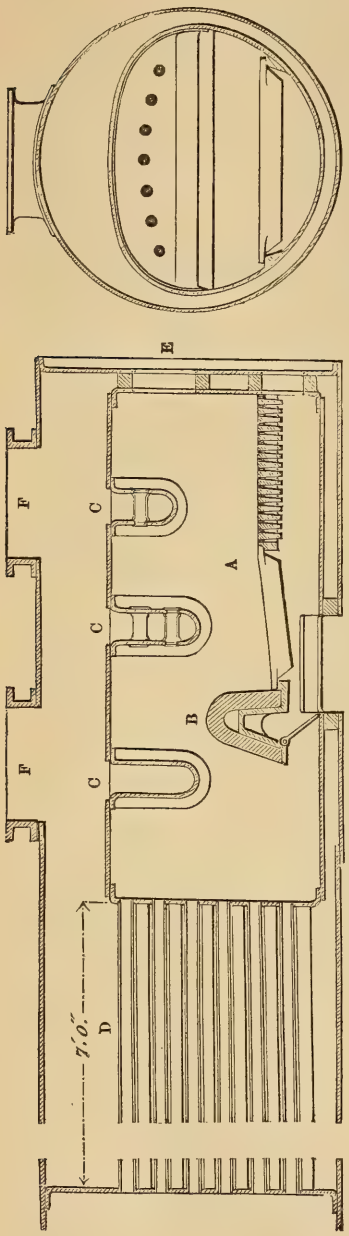


Fig. 392.—Long Fire Box, fitted with Inclined Deflectors. Longitudinal and Transverse Sections.

A, Fire box. B, Fire-brick bridge. C C C, Water spaces. D, Tubes in the body of boiler. E, Furnace door. F F, Holes of manhole and dome.

flame acts on the crown of the fire box more beneficially. In all these examples having stay tubes placed in the wall of the fire box, it is necessary to fit sliding bars so as to regulate the supply of air necessary to effect complete combustion with the different kinds of coal used, or to admit more or less air as may be required with the same kind of coal, owing to atmospherical changes.

In some railways a long elliptical fire box has been adopted (Fig. 392), having a fire-brick bridge at the back similar to the Cornish boiler, through which air is admitted by a number of apertures. There are also hanging water spaces fitted to the crown of the fire box for deflecting and mixing the gases, thus detaining the flame in its passage to the tubes placed in the body of the boiler. Stay tubes are likewise placed in these hanging bridges, which greatly strengthen them, besides affording free passage for the flame and gases, and which seem fully to meet the views of the designer.

Another plan has merely a long elliptical fire box, having a diaphragm of fire brick placed at the back of the fire bars, the flame passing through suitable openings left in the diaphragm. This plan has the advan-

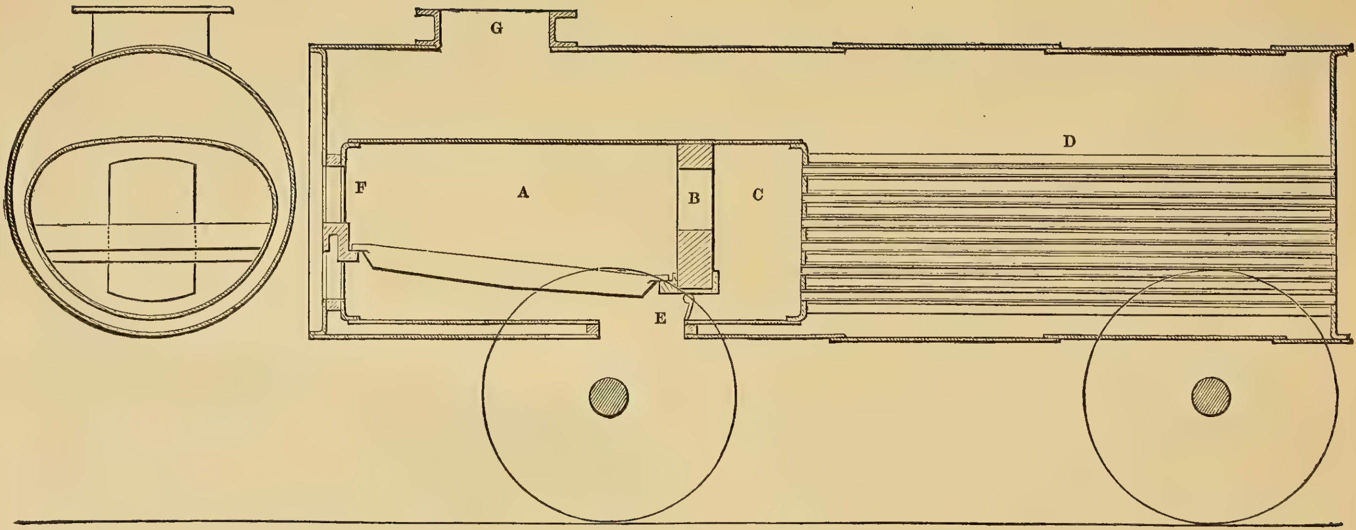


Fig. 393.—Long Fire Box and Combustion Chamber. End View and Longitudinal Section.

A, Fire box. B, Diaphragm of brick. C, Combustion chamber. D, Tubes in the body of boiler. E, Damper for admitting air into the combustion chamber. F, Furnace door. G, Manhole.

tage of a separate combustion chamber, to which air is admitted through a damper placed at the bottom of the diaphragm.

Steam-inducted currents of air have been successfully adopted for the prevention of smoke, the air being forced through stay tubes placed on the side walls of the fire box, eight of these hollow stays being placed on one side and seven on the opposite side. By this arrangement the currents of air (proceeding from these stay tubes) do not interfere with each other, as would be the case were the tubes placed exactly opposite each other, when the current of the one impinges against the current of the other, whereas in the arrangement shown the current passes across the whole width of the fire box. The air can be inducted into the fire box at an angle by merely inclining the stay tubes, and the arrangement is fitted with steam pipes and nozzles, or small jets, as has been already described. This plan has many advantages, the principal of which are, the easy mode of regulating the supply of air to suit the requirements, and that there are no mechanical difficulties in keeping the apparatus in efficient working order.

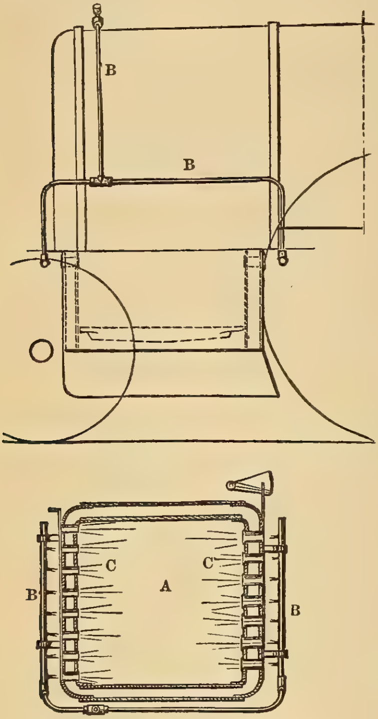


Fig. 394.—Steam-inducted Currents of Air.

A, Fire box. B, Steam pipe and jets. C C, Tubes.

Steam highly superheated has been blown over and through the coal in the fire box for the suppression of smoke, and when this plan is carried out properly it has been attended with success so far as the smoke is rendered nearly invisible; but there can be no doubt that unless the steam is highly heated, in combination with fine rapid streams of air passing through the fire door, that the mere fact of blowing raw steam over or through the fuel damps the fire, and consequently retards combustion, rendering it both more expensive in fuel for the production of steam, and keeping such apparatus in efficient working order.

It is evident that in all the foregoing examples the main thing that has been studied is the utilization of the smoke and gases in the production of steam, by a due admixture of air passing into or inducted into the furnace or combustion chamber. It must be borne in mind, however, that a little smoke may issue at the top of the chimney with the most perfect arrangements, when the engine is not working; but when the engine is in motion, the *vapour*, erroneously termed steam, issuing from the blast pipe, completely annihilates the smoke. This is easily explained: the vapour when seen is of a snowy whiteness, and we all know that a little dirty water can be made much clearer with a copious admixture of pure water; the same with the smoke. It gets mixed up in the chimney with the vapour from the blast pipe, and the latter absorbs the smoke and becomes more or less coloured with the sooty particles. Smoke nuisance at railway stations is of more importance to get rid of. This is accomplished by turning on the blow pipe placed in the chimney, the primary use of which is to urge the fire while the engine is not working, supplying oxygen, so necessary for combustion, by forming a partial vacuum in the chimney as already described.

It is allowed by all that careful firing is the chief practical difficulty to attend to in effecting the complete combustion of the gases and the prevention of smoke. The fuel should be supplied at short intervals, in small quantities, equally distributed. With inclined grates the fuel is laid on near the fire door, and is fed on the grate *per se* by gravitation; thus the stoker's duty is comparatively easy compared with the ordinary kind of fire grate lying quite flat. In fact, with inclined bars the continuous forward motion of the fuel keeps the fire grate always covered, and is the nearest approach to continuous firing with travelling fire grates, without the inconvenience of such mechanical contrivances,—not at all to be desired in the locomotive engine, although for other purposes moving fire grates answer admirably.

It is of primary importance that the fire box of a locomotive-engine boiler should be so constructed as to allow of a copious supply of air above the fuel for the combustion of the gases, and that the air should freely mix with the gases to give the greatest effect. To attain this object, length of fire box, breaking up of the flames by the interposition of fire tiles, fire-brick arches, baffle plates, and other similar contrivances, are effectual, all tending to delay or lengthen the run of the flame and gases in the fire box before entering the tubes in the body of the boiler. It must be likewise borne in mind that the air should be admitted at a high temperature to attain the greatest measure of economy; this has been effected in a variety of ways. Some have placed an air chamber in the smoke box, in connection with tubes carried along to the fire box; by this means the air is heated before passing into the combustion chamber. Others have placed tubes, carried from the front of the smoke box through the water space in the boiler; thus the air is partially heated before entering the fire box. This plan slightly tends to reduce the temperature of the water in the boiler, and consequently the steam pressure. Auxiliary furnaces for heating the air, as likewise fire-brick tiles placed in the combustion chamber, have been carried out with a measure of success. A hot-air blast, promoted by the steam blast in the chimney, is far more economical, and tends more to effect the complete combustion of the smoke and gases, than simply admitting currents of cold air, however finely they may be spread over the surface of the incandescent fuel where the heat is the greatest. With air inducted by steam jets the air is partially heated in its passage through the short tubes placed in the walls of the fire box; and there can be little doubt that if the steam was superheated before passing through the jets a greater measure of economy would be the result. The tubes to carry out this plan may be 2 inches in diameter, and their combined area should give 4 inches of tube area to every square foot of fire grate, which of course can be reduced or regulated according to the requirements by means of the sliding bars, worked by hand from the engine platform. This plan of steam-inducted currents of air is simply a number of miniature nozzled steam blast pipes, similar in action to the main steam blast placed in the chimney; the action of the one is almost identical with the action of the other, each having the power of inducting the air into the fire box. The former, however, forces the air in currents of more or less intensity across the fire box, as may be required. Thus it is thoroughly mixed with the gases immediately where it is wanted; and it is remarked that where the fuel lies in the line of these currents it is scooped or grooved out—a convincing proof that the admission of air freely above the fuel, or even partially through it, is the one effectual way to cause complete combustion.

The practical working of the apparatus now claims our attention. When a sufficient area of tubes is provided it is not necessary, under ordinary circumstances, to turn on the steam jets while the engine is running, as a sufficient quantity of air will be drawn into the fire box through the tubes by the action of the main steam blast placed in the chimney; but when the vapour issuing from the chimney appears dense, it is evident that the combustion of the smoke and gases is not perfect in the fire box, and the steam inductor can then be turned on with advantage. In the same way, when approaching stations, and the steam is turned off the engine, combustion receives a check owing to the blast having ceased, and although the fire is burning with great intensity, smoke may issue at the chimney, which can be prevented by turning on the steam-inducting current, thus providing the necessary oxygen for consuming the smoke in the fire box.

The problem for effectually utilizing coal in the locomotive-boiler furnace—carrying out complete combustion, so far as practicable—is thus solved by the free admixture of heated air with the smoke and combustible gases, the air being inducted into the fire box at or near the surface of the fuel.

THE BRITISH LOCOMOTIVE.

CONSTRUCTION OF THE BOILER AND BOILER MOUNTINGS.

In the practical construction of the locomotive boiler the *fire box* is of the first importance. Its outside shell is made of iron, and the inside shell or fire box proper of copper, or in some instances of iron. The fire box proper is surrounded with a water space, communicating freely with the other internal water spaces in the boiler. The union between the fire box and the outside shell at the bottom is effected by means of a wrought-iron frame of a square section. This frame is drilled with holes to correspond with the rivet holes in the plates, all of which are rivetted together and made perfectly steam tight by caulking the edges of the plates. Sometimes a U or other section formed of boiler plate is adopted, as the long rivets which must be used with the solid form are liable to leak. The flat sides of the fire box and outside shell, being exposed to the full boiler pressure, are not of sufficient strength to resist the stress; and as the strain is in opposite directions, screwed stays are introduced, binding the inside and outside shells together. These stays are generally made of copper, and are pitched closely together; after being screwed hard into the holes tapped for their reception, their ends are rivetted over, thus materially increasing their holding power. They are screwed for their entire length; when so made it necessarily takes a long time to screw them into the plates. The stays are sometimes turned down at the middle (Fig. 397), making their diameter smaller in the middle than at the ends, and so dispensing with the thread except at each end,

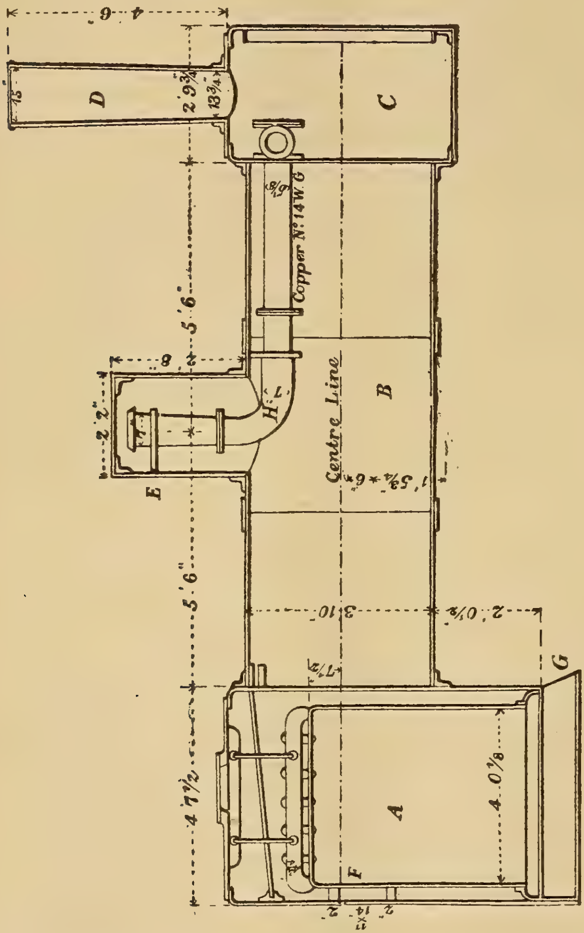


Fig. 395.—The Boiler.

A, Fire box. B, Body of boiler. C, Smoke box. D, Chimney. E, Steam dome. F, Furnace door. G, Damper. H, Steam pipe.

and giving elasticity to the stay. This to a slight extent may be advisable, but it should be borne in mind that the middle part must be of sufficient strength to resist the direct pressure, and we believe that the elasticity of stays in narrow water spaces is but of little moment. The unequal expansion of the fire box, however, over that of the outside shell must throw a greater bending stress on the top stays than those at the bottom; the ends of the stays, therefore, to meet the strains imposed, should be of larger diameter than the middle of the stay, and the extra cost of their manufacture is balanced by the ease and less time taken to screw them into the plates. Of course the direct cohesive strength of all stays subjected to tension is measured by the diameter of the stay at the bottom of the thread, and when the threads are turned off to the diameter at the middle of the stay, the cohesive strength remains the same, while the elasticity is greatly improved. The top of the fire box must necessarily be strengthened with a very different form of stays, as it would not be convenient to connect it to the top of the outside shell in the same manner as the sides, although in some instances long screwed stays have been tapped through the top of the outside fire box and the crown of the inside one. Therefore the top is prevented from collapsing by means of solid bars of wrought iron, placed on edge along the top of the fire box, with projections forged on for resting on the edges of the plates forming the fire box. The bearing surfaces, in some instances, are merely the breadth of the bar iron; but as the power to resist compression in copper is very low, about 3 tons per square inch, it is obvious that the bearing surfaces should be made of sufficient area to meet the requirements. These bars have bosses

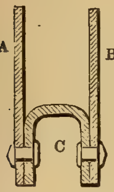


Fig. 396.—Plate of a U form for the bottom of Fire Box.

A, Fire-box plate. B, Outside fire-box plate. C, U piece.

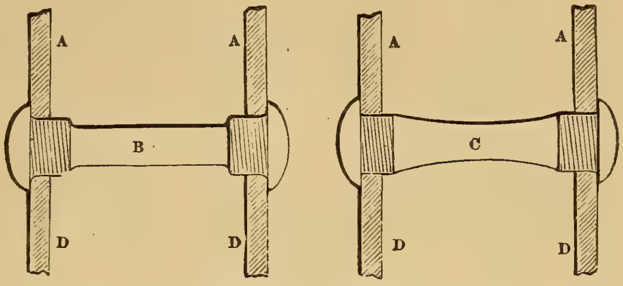


Fig. 397.—Fire-box Stays.

A A, Plates. B, Parallel stay. C, Curved stay. D D, Screwed parts.

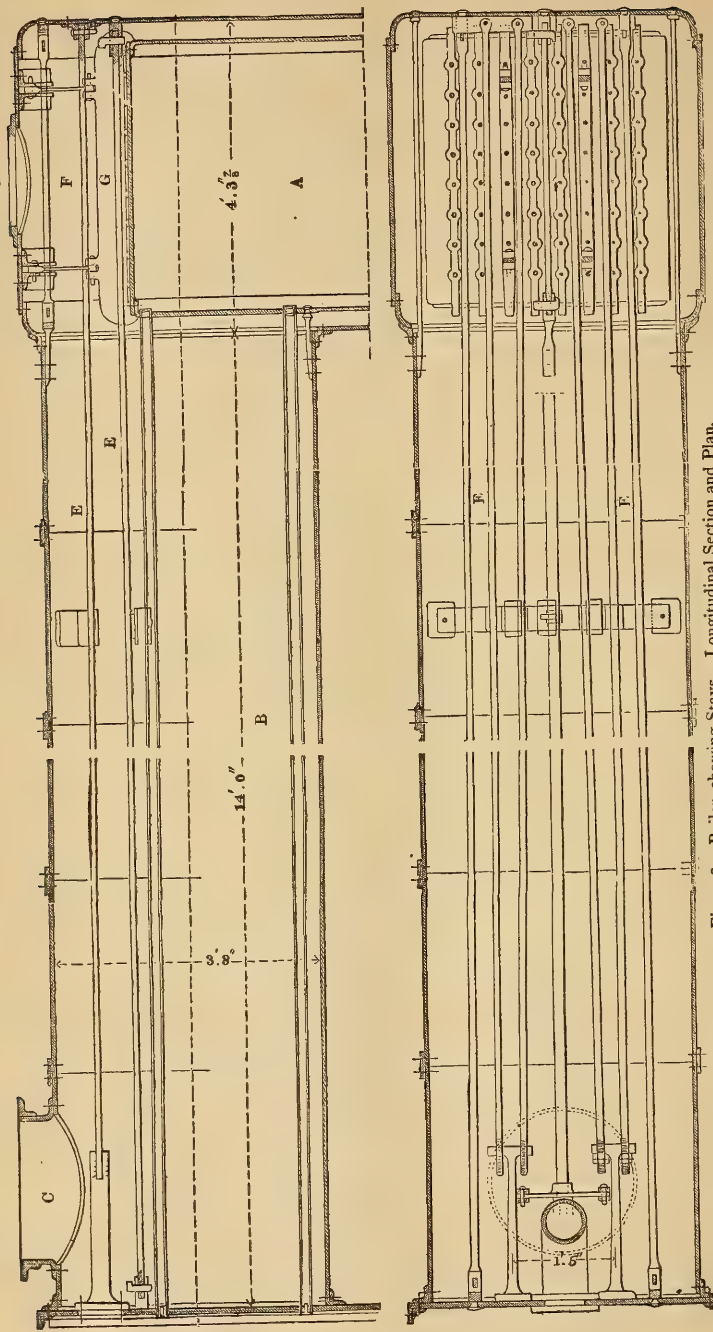
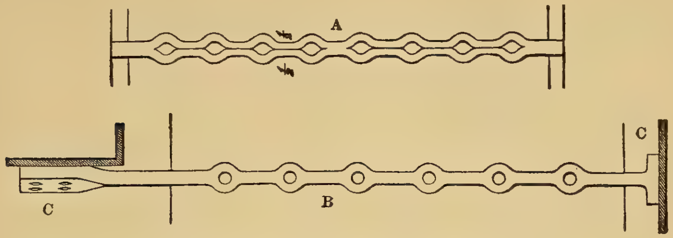


Fig. 398.—Boiler, showing Stays. Longitudinal Section and Plan.

A, Fire box. B, Body of boiler. C, Hole for dome. D, Manhole. E E, Longitudinal stays. F, Stays between front and back of the outside shell of fire box. G, Beam stays on the top of fire box.

forged on at short intervals, which are bored for the reception of stay bolts passing through the top of the fire box, deep washers



Figs. 399, 400.—Stays for top of Fire Box.
A, Plate stay. B, Stay forged solid. C C, Palms.

being interposed between the plate and bottom of the bars, while in some projections are left on the forging. By this means the top plate of the fire box is drawn tightly up against the bottom of the beams or stay bars, and a bearing is secured at short intervals along the entire length of the stays. By this arrangement the strain on the plate is not too great, otherwise the plate would be drawn up, which these washers effectually prevent, and a free circulation of the water under the stays is effected, preventing the plate being injured by the intense heat. Sometimes palms are forged on for rivetting to the outside shell of the fire box and body of the boiler.

In some examples the stays are made of wrought-iron plates rivetted together, and indented where the bolts pass through. As a means of staying the top of the outside shell, vertical bars are introduced, secured to the beams on the top of the fire box by a joint and pin taking a lug forged on the beams, while the top end is secured to a T iron bar rivetted to the shell, the pin for the joint passing through the mid feather of the T iron. Longitudinal stays secure the smoke-box tube plate and the outside shell of the fire box, as shown in Fig. 398.

The next detail in connection with the fire box is the junction of the apertures cut out in both of the shells to form the fire doorway. This was formerly effected by means of a solid bar of iron around the opening, which is generally elliptical, securely rivetted between the inside and outside plates. This plan necessarily entailed very long rivets, and sometimes gave great trouble owing to leakage. To obviate that objection, as likewise to obtain a free water space at that part of the fire box, the junction between the shells has been improved by the introduction of a distance piece formed of plate iron, flanged for rivetting to the inside box, while an angle iron is worked all round the mouth-piece on the outside, being properly rivetted to it and to the outside shell. To form the openings for flues between the fire box and combustion chamber, where such a chamber exists, the distance pieces between the fire box and the combustion chamber must be of a U section, of plate iron, interposed between the plates of the fire box and chamber, as in Fig. 402, so that they may be in contact all round with the water, otherwise the intense heat of the fire box or chamber would burn such portions of the distance pieces as were not thus protected. The fire door is made of plate iron, hinged to the outside shell of the fire box, and is provided with a latch for shutting it close. There is a baffle plate fitted inside, which is kept apart from the door with ferrules and rivets, forming an air space, thus protecting the door from the intense heat of the furnace.

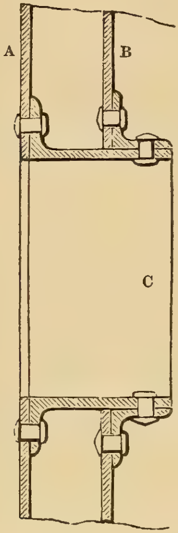


Fig. 401.—Fire-door Opening.

A, Inside plate of fire box. B, Outside plate of shell of fire box. C, Furnace doorway.

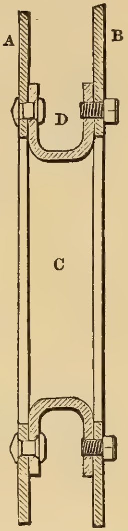


Fig. 402.—Fire-door Opening.

A, Inside plate of fire box. B, Outside plate of shell of fire box. C, Furnace doorway. D, U piece.

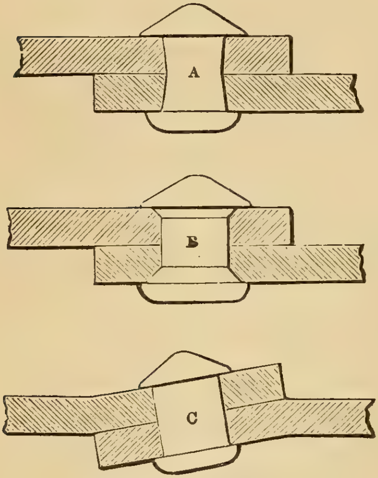
The next constructive detail with reference to the fire box is the manner of securing better work and facility for cleansing at the bottom corners. With this object part of the outside shell is cut out at the corners, and a thicker forged plate worked on, having a raised boss with tapped hole for the reception of a sludge screwed plug, which would be otherwise difficult to adjust. There can be no doubt that these sludge taps placed at each corner give great facility for cleansing these contracted water spaces from deposit by means of a water hose.

On the top of the outside shell a short branch piece is worked, made of plate iron, flanged for rivetting to the shell, and fitted with an angle iron at the top. This aperture in the shell is to allow the steam to enter the steam dome or receiver when so fitted, or for the reception of the plate on which the safety valves are placed. This plate also forms the manhole door, and can be taken off to admit of inspecting the inside of the boiler. In working the plates of the outside shell, the front and back ones are flanged for taking the top and side plates; the flanged corners should have bold curves, and should not be worked square, as that form greatly distorts the fibre of the iron, and consequently weakens the strength of the plate. Of course all these flanged plates must be drilled, or punched by a hand machine termed a *bear*. All the rivetting up should be executed between the outside and inside fire boxes, before the holes are drilled through both shells for the reception of the screwed stays already referred to.

It is necessary to fit an ash pan underneath the fire bars. The use of this pan is chiefly to prevent the cinders and live coal from falling on the line, more especially on viaducts which have a flooring of timber, as in some cases bridges have caught fire from the live coal falling from the fire grate. This ash pan is secured to the outside shell, and is fitted with a damper for regulating the supply of air to the furnace when the engine is running, or for shutting off the supply when the engine is standing, as may be required. In some instances dampers are fitted to the front and back, more especially in countries subjected to great falls of snow. This is very desirable when engines are run tender-first for a considerable journey, in which case the front damper can be shut, and the back one opened, for, with much snow on the line, if the front damper was not closed the ash pan would get choked with the snow. In this case the hind damper admits the air underneath the fire grate, but it of course cannot act so beneficially in promoting a rush of air underneath the grate as the front damper. With the engine running at a high speed the pressure of the air against the moving surface provides a powerful blast, which, with the front damper open, affords a very effectual means for supplying air to the fire grate.

The fire bars of the locomotive boiler are formed of wrought iron of a thin deep section, and are supported by a wrought-iron frame, which should be fitted with hinges or otherwise, so that it can be dropped easily for the removal of clinker.

The shell of the boiler is of a cylindrical form; a ring of angle iron is worked on at each end for rivetting it to the outside shell of the fire box and front tube plate respectively. In some cases the plates of the outside shell of the fire box are flanged, to which the shell of the boiler is rivetted, thus dispensing with the angle-iron ring.



Figs. 403, 404, 405.—Rivets.

A, Rivet hole formed conical in the act of punching. B, Countersunk holes. C, Joint spread out.

The longitudinal joints of the shell are usually double rivetted, and the circumferential joints single rivetted; but others have single rivetting for the longitudinal and circumferential laps. The rivets are ¾ inch in diameter, pitch 2 inches, for plates from ⅜ to ½ inch, while for thinner plates the pitch is 1¾ inches, and for rivets $\frac{11}{16}$ inch the pitch is 1⅝ inch. The holes are all punched, and in punching they assume a conical form; the small ends being placed together, the rivet when properly filling the hole becomes a double cone, which greatly strengthens the rivetting and stiffens the joints—converging the line of strain through the plates. The rivet holes are sometimes countersunk, and when the rivets are made accordingly the strength is greatly increased, for should the head be destroyed by corrosion the countersink will hold good. As the joints in single rivetting are liable to twist, the plates are sometimes spread out, getting the line of strain more directly through the line of plating.

There can be no doubt that the longitudinal seams ought to be much stronger than the transverse ones. To attain this object the plates are made to butt together, and fitted with strip iron double rivetted, thus having four rows of rivets. A small piece is worked on the ends of the strips in the inside, making them very strong at that part, and much more easily caulked. The double-rivetted welt joint, made of Lowmoor plate, is capable of bearing a strain of nearly 9000 lbs. per square inch of sectional area, and as the longitudinal seams have to bear a stress of about double the other seams, the double-rivetted longitudinal joints are nearly equal in strength to the other joints single rivetted, and in practice may be taken at equal value.

The plates for the shell are all planed on the edges, and are slightly bevelled for setting up, the caulking making them quite flat. Great care must be taken in this operation, as undoubtedly the caulking has a tendency to buckle the plates, thus weakening the joints. Scarf-welded joints have been successfully introduced. The plates are planed on the surface to fit each other, and are then heated on both sides, and hammered as in ordinary welds, very little hammering being required. When the work is properly executed, this is no doubt the strongest way of uniting boiler plates; moreover, the reduction of weight and the non-liability to leakage is greatly in favour of this plan in its application to shells or other boilers.

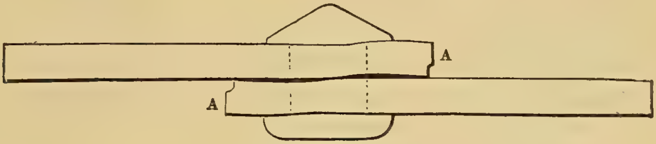


Fig. 406.—Lap Joint.

A A, Exaggerated effect of caulking.

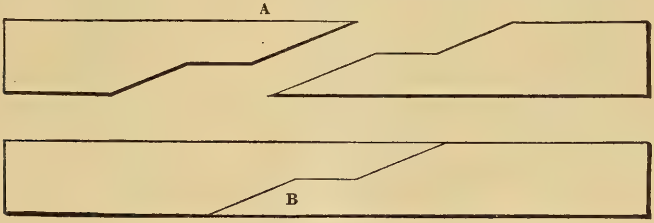


Fig. 407.—Scarf-welded Joint.

A, Scarf plates apart. B, Scarf complete.

The *steam chest* is a short round barrel, placed at the centre of the top of shell or at the front near the chimney, and in some instances on the top of the outside fire box. A short piece is flanged and rivetted to the top of the fire box; on the top of this piece an angle iron is worked, which is turned on the top surface for jointing to the turned angle-iron surface on the steam chest, the two flanges being bolted together, and these can be readily disjointed, forming a manhole for inspecting the inside of the boiler. When the steam chest is placed on the shell an angle iron is worked on it at the bottom, and securely rivetted to it and the shell; on the top of the steam chest a cast-iron plate, on which are the safety valves, is fitted. This can be taken off at pleasure for inspecting the stop valve and other parts of the boiler. In such an arrangement it is usual to fit a manhole door on the top of the fire box, on which the steam whistles may be placed.

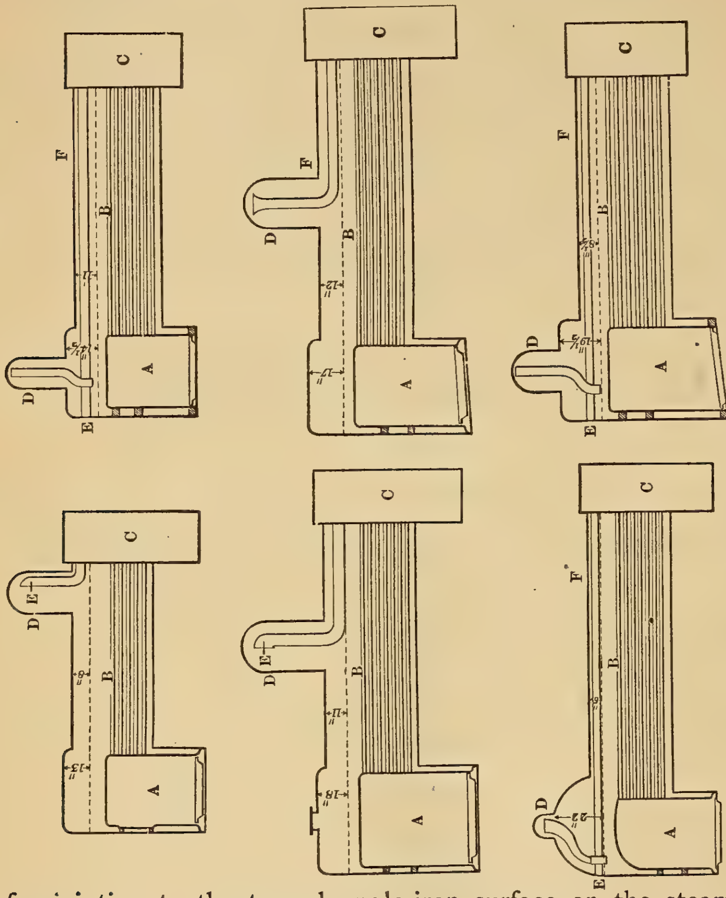


Fig. 408.—General Arrangement of Boilers, showing the position of the Fire Box, Tubes, Smoke Box, Steam Chest, and Steam Pipes inside the Boiler.

A, Fire box. B, Tubes. C, Smoke box. D, Steam dome. E, Regulator. F, Steam pipe.

On all the parts of the shell where the check-valve boxes for the feed pipes are fitted, forged plates having raised bosses are securely rivetted to the shell. By this means the joints for the check-valve boxes are made on turned surfaces, instead of fitting the flanges to the curved plates of the shell—a plan which secures good joints, and greatly facilitates the jointing and disjointing of all the valve boxes, plug taps, &c.

The *brass tubes* are generally 2 inches in diameter and from 10 feet to 12 feet in length, with a thickness of from 9 to 14 wire gauge, or nearly ⅛ inch thick. The arrangement of the tubes is of the highest importance. Sufficient room should be given for the free circulation of the water. It is obvious that with a large water space between the tubes and the side of the shell of the boiler, the water has a better circulation than when the tubes are packed too closely; and that small water spaces between the tubes, in combination with a mass of tubes, tends greatly to decrease the evaporative power of the heating surface, as delineated in the circle having the largest number of tubes. The holes in the front plate of the fire box, and tube plate in the front of the shell, being all set out accurately, arranged zigzag or triangular and not above one another, as in marine boilers, having water spaces between from ½ inch or ⅝ to 1 inch, are then drilled for the reception of the tubes. These are driven tightly in, and then expanded with a tool for the purpose; the ends are then rivetted over, making them perfectly steam tight. They are rendered secure by driving in wrought-iron ferrules at the fire-box end, while every six or so of the tubes at the front end are likewise ferruled; but some are not so, giving free passage for the soot and small cinders. Thus the tubes, being firmly held at the ends, act as stays, tending to prevent the tube plates being forced outwards by the pressure of the steam. However, long tie stays must be placed above the tubes, running the entire length

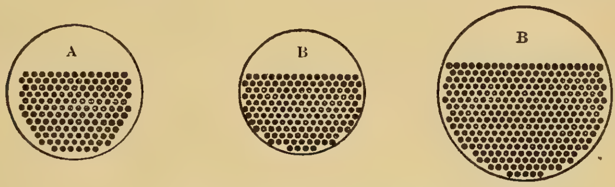


Fig. 409.—Arrangement of Tubes.

A, Free circulation at sides. B B, Contracted at sides.

of the boiler, between the back plate of the fire box and the tube plate in front of the shell. Gusset stays are sometimes applied in the angles of the fire-box shell, uniting the flat plates with the cylindrical portion of the boiler; thus the through tie bars may be dispensed with—those gusset plates being likewise fitted to the tube plate in the front of the shell.

The *smoke box* is usually made cylindrical. It is formed of ¼-inch plate iron, rivetted to the flanged tube plate on the shell, this plate being carried down for securing the back flanges of the cylinders. The front plate of the smoke box may be flanged, or an angle iron worked at the corner for rivetting to the shell of the smoke box. The door for the smoke box should be of sufficient diameter to admit of the tubes being angled with the holes drilled for their reception; the hole in the plate is turned out with a slight bevel, and the door is accurately turned to fit, an angle iron being worked inside to stiffen the plate, and prevent it buckling with the heat; an inside plate is likewise fitted to the door for its protection. The door is secured in its place with generally three sliding bolts, jointed to a central disc plate, worked by a handle placed outside of the door, the door being hinged to the end plate of the smoke box, with one long bolt taking both of the hinge plates and studs secured to the smoke box.

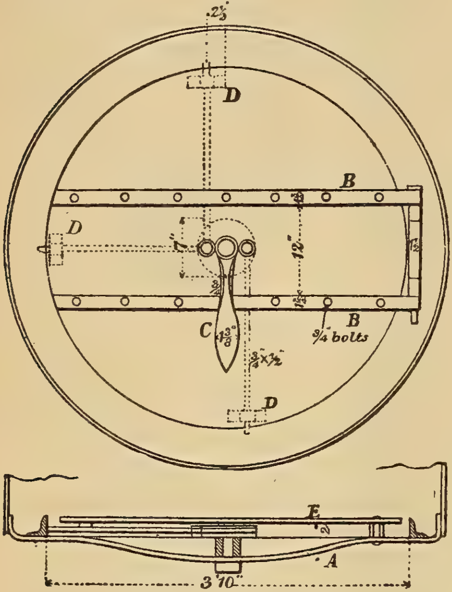
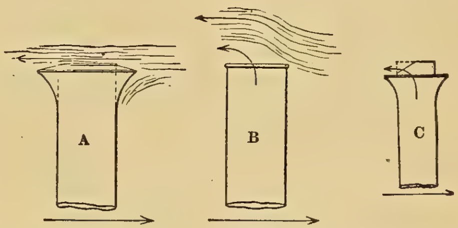


Fig. 410.—Smoke-box Door.
A, Smoke-box door. B B, Hinge plates. C, Handle.
D D D, Sliding bolts. E, Inside plate.

The *chimney* is usually made single, but at times an inside tube is introduced to prevent condensation and preserve the full force of the blast. The tube generally tapers from the bottom upwards; thus the steam from the blast pipe expands in its upward course, consequently the vapour and smoke issuing from the top are not of such density as at the orifice of the blast pipe, where the chimney is contracted. The inside of the smoke pipe should be quite plain; the rivet heads should be countersunk into the plate covering the joints, so that there will not be any obstruction to the passage of the steam and smoke. The outside covering can of course be rivetted in the usual manner; it is secured to the top of the smoke box by a short flanged plate rivetted to the chimney, and bolted to the smoke-box shell. At one time the top of the chimney was ornamented with a finely curved cap made of copper, which was kept bright, while others were formed of a wrought-iron plate, and as such presented a very neat appearance; but as the top of the chimney, when properly formed, stimulates the draught passing through the fire box when the engine is running fast, it is of importance to form the top with this object chiefly in view; and we certainly consider the plain top, cut quite horizontally, is the best form that can be adopted, slicing the air, as it were, cleanly, while with the curved form the air impinging against the top is thrown downwards. Some have bevelled the top backwards to facilitate the escape of the vapour and smoke, and assist the draught, never taking into consideration that when so formed, with the engine running backwards, a downward current of air passes into the chimney, tending to impede the draught; moreover, a strong side wind must necessarily affect the draught with such a form.



Figs. 411, 412, 413.—Chimney Tops.
A, Curved top. B, Plain top. C, Curved top with part bevelled off.

The *ash pan* is made of plate iron ¼ inch in thickness, framed with angle iron, having a band of flat iron at the top. The depth should be at least from 9 to 10 inches, so as to hold a large quantity of ashes, giving a sufficient air space above the ashes for the admission of air underneath the furnace bars. It should fit closely to the bottom of the fire box, otherwise the draught will be impaired. The ash pan is sometimes fitted with dampers at the front and back, as already explained, the damper being a flat plate hinged at the top, and closing accurately the aperture when shut. It is fitted with a lever and rod, by which it is opened or shut from the platform; and can be used either to stop the draught by shutting it completely, or nicely to adjust the quantity of air required underneath the grate. It is generally bolted or rivetted to the fire box with straps for that purpose, and sometimes a small door is fitted at the bottom to allow the ashes to fall down, thus conveniently clearing the ash pan. A disc damper should be placed at the crown of the smoke box to damp the fire effectually at that end. Venetian dampers have been successfully applied, covering the ends of the tubes in the smoke box, while some are contented with placing a plate on the top of the chimney, which must be removed before starting the engine. Undoubtedly the locomotive boiler furnace should be damped at both ends when required, which is practically carried into effect with the damper on the ash pan, and otherwise in the smoke box or chimney.

The *fire bars* are of wrought iron from ⅝ to 1¼ inch in thickness; the latter size is thinned at the bottom edge to about one-half of the thickness. The general thickness adopted is from ⅝ to ¾ inch, with equal air spaces between them; this thickness being found best in practice, as the bars are not so liable to twist, being more easily kept cool. They should not be thinned when of this thickness, but merely chamfered on the lower edge for the free admission of air. For bars of 3 feet long and under, the depth varies from 3 to 4½ inches; when of greater length they must be made in two lengths, or supported at the middle with a cross bar. The bars are cut and flattened at the end, with raised pieces forged on the sides, so that they may be kept apart the necessary width for the admission of air. The frame on which the bars rest is made of wrought iron, 1 by 1½ inch deep, fitted all round the bottom of the fire box quite close up to the rivet heads, and is held up with studs rivetted to the fire box. Some place angle iron for supporting the bars, which is rivetted to the fire box, and notched for the bars, by this means keeping them apart without any forged projections on the bars. When the bars are not put in one by one it is preferable to hinge the whole grate, so that they may be dropped down entire, as sometimes a few of the bars may be choked up with clinker or impure matter from the fuel, and consequently if only a few were hinged there might be a difficulty in dropping them.

We give a very good plan adapted for a double fire grate (Fig. 414). The frames for holding the bars are slightly inclined, and rest on projections rivetted to the fire box, and at the bottom end projections are forged on the frames, which rest on projections forged on a bar

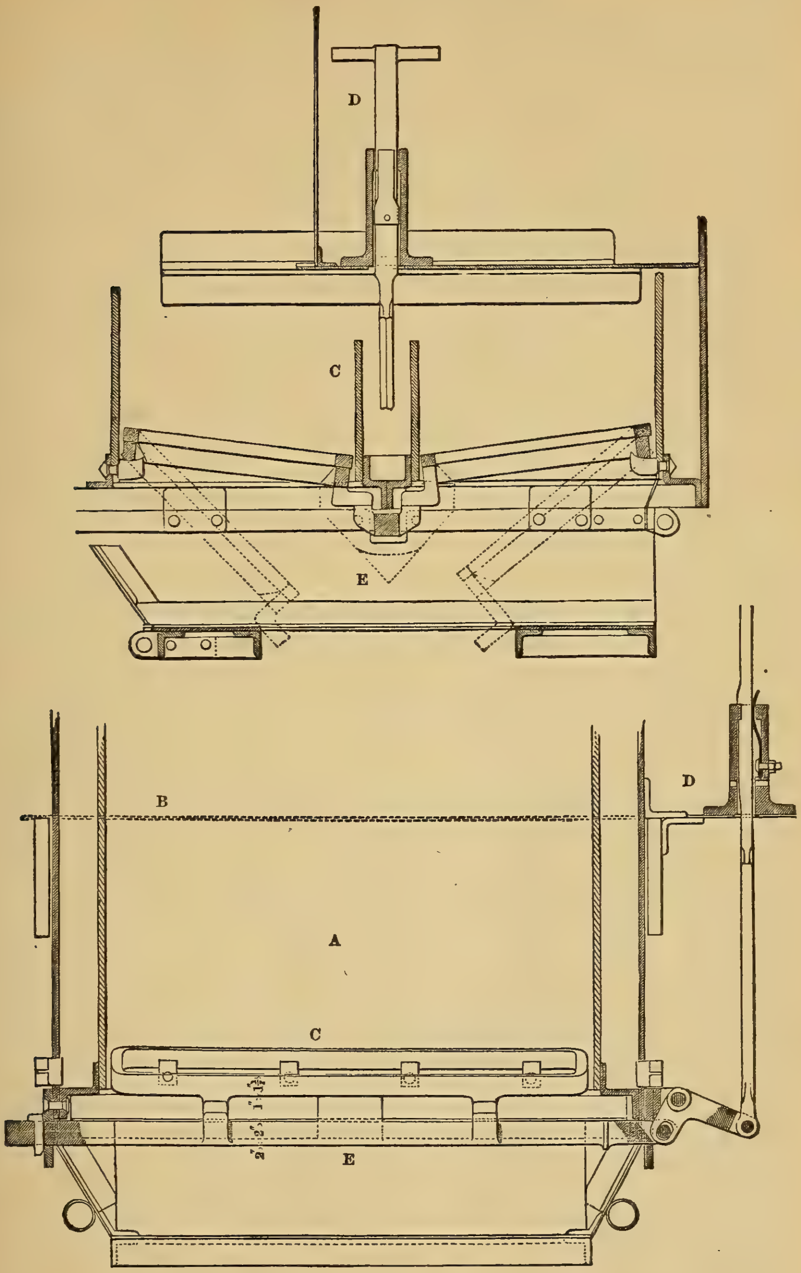


Fig. 414.—Arrangement for Lowering the Fire Bars.

A, Fire box. B, Foot plate. C, Fire bars. D, Handle, rod, lever, &c. E, Ash pan.

running across the bottom of the fire box. This bar is made to slide in suitable hanging pieces rivetted to the fire box, and at one end there is a bell-crank lever having a rod and handle passing up to the foot plate. When the bars require to be dropped the handle is pulled up, and the pin on the end of the bar having been removed it is drawn past the projections, and then the frames and bars fall down. In this arrangement there are no hinges, and consequently less liability to derangement.

The *brackets* for supporting the boiler from the frame are generally made of plate and angle iron; at the smoke-box end and body of the boiler, these brackets are rivetted to the frame, but at the fire-box end the boiler is free to expand, sliding as it were on the frame, yet firmly held thereto with bolts and nuts. The bracket on the body of the boiler should not be made too rigid, otherwise a severe strain would be thrown on the framing. The plate bracket should be of a certain elasticity, to yield to the expansion and contraction of the boiler. Unless this is provided for, rupture may take place in the seams of the boiler. Sometimes the boiler merely rests on this bracket, without being rivetted. The brackets for the smoke-box end are simply extensions of the tube and front plate, stiffened with angle iron, when the arrangement of the machinery will admit of this; and in some there is simply an angle iron rivetted to the smoke box, which is carried down square at the sides, with an inverted angle iron rivetted to the frame, and the two secured with bolts and nuts. The bracket for the body of the boiler is of plate iron, secured to the under side of the boiler and to the main framing; while for the fire box some provision must be made for the expansion and contraction of the boiler.

To *prevent radiation* and condensation of the steam in the boiler it is covered with a non-conducting material, consisting of felt wrapped round in several plies, having wood-lagging over all, consisting of pine battens grooved and tongued, and secured to wooden rings which are fastened to the boiler with screws; over the lagging is placed sheet iron, which is banded at the transverse joints with hoops of the same material, to which lugs are rivetted at the ends, which are bored out and tapped for the tightening-up screw, thus holding the felt and covering boards firmly in position, the parts lagged being the body of the boiler, the top and sides of the outside shell of the fire box, and the dome.

The *steam pipe* inside of the boiler is made of copper, about ⅛ inch in thickness, having brass flanges soldered thereto for making the joints, the flanges being sometimes grooved and filletted. The pipe is held up with straps rivetted to the crown of the boiler where necessary, and in most locomotives is carried up inside of the dome, with the object of getting the steam made as dry as possible; while with some arrangements there is no dome, the steam pipe traversing the entire length of the boiler, the pipe having a number of slits cut out in it. By this means the steam is taken into the pipe immediately over the parts where it is generated; thus drier steam is obtained. However, the general practice is to provide a steam dome, having the pipe carried to the top, on which is fitted the regulators, made of brass. Circular-disc regulators have been adopted, rotating on a centre pin: this plan is not much in use, as the surface wears unequally, the circumference of the disc plate having a greater travel than the centre, consequently more wear must occur at the edges. Flat gridiron valves sliding over ports are very generally adopted, fitted to the top of the steam pipe inside of the dome, or placed directly on the cylinders in the smoke box; the former position is to be preferred, as with the latter there is a constant pressure of the steam in the pipes in the smoke box, tending to leakage. The fewer joints to keep tight in so complicated a machine as the locomotive engine the better. An improvement on the former plan consists in placing the regulator in a cast-iron box, bolted to the tube plate on the end of the steam pipe. By this means, when the engine is standing or the valve closed, the pipes in the smoke box are relieved from the pressure; the rod for working the valve passes through the inside pipe, and is actuated by a lever directly, the rod being provided with a stuffing box fitted to the back plate of the shell of the fire box. There is no steam dome in this example, and the pipe is slotted with a number of apertures for taking away the steam immediately over the parts where it is generated. However, the arrangement suits equally well when a steam dome is fitted, having a pipe at right angles for taking the steam from the top of the dome.

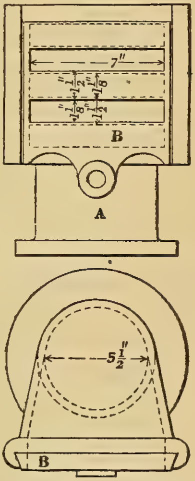
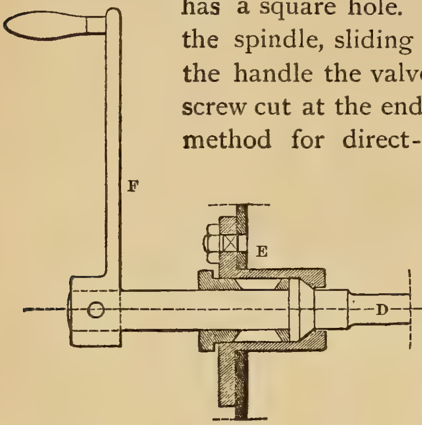


Fig. 415.—Gridiron Regulator. A, Chest for valve. B, Gridiron valve.

When the engine is standing, or the valve shut, the pipe is not subjected to pressure, the only part subjected to pressure being the cast-iron box. Double-beat valves have been arranged in a similar way to the foregoing, having a screwed spindle for opening the valve, which is actuated by a lever, handle and rod; the latter passes through the centre of the steam pipe, and has a boss forged on it, which has a square hole. This receives a square part on the spindle, sliding freely thereon; thus by turning the handle the valves are opened and shut by the screw cut at the end of the valve spindle. Another method for direct-action regulators has a brass circular box bolted to the back of the fire-box shell, having a circular cylindrical valve with a conical seat at the end. The handle for actuating the valve works in a spiral segment; the handle being turned presses against the side of the spiral segment, thus pushing the valve firmly against the seat; and on being turned the other way the handle bears on the opposite side of the segment, thereby opening the valve. With this arrangement the inside steam pipe is subjected to the steam pressure, tending to collapse it, that is to say, when the valve is shut. Double-beat valves arranged vertically are very generally used



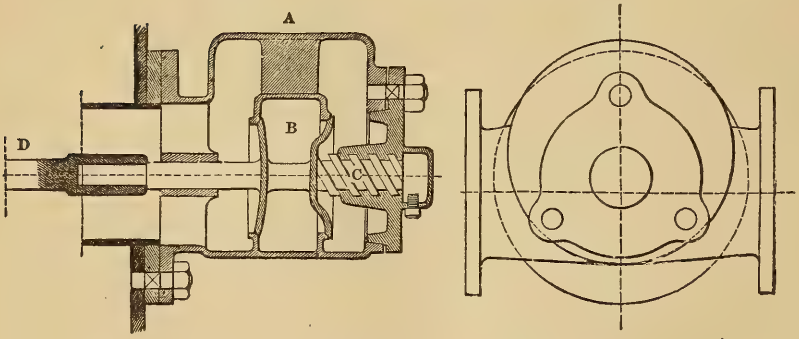


Fig. 416.—Double-beat Valve Regulator.

A, Valve chest. B, Double-beat valve. C, Screw on the spindle. D, Rod. E, Stuffing box. F, Regulator handle.

for the regulator; a strong cast-iron pipe is fitted to the steam pipe, at the top of which a short piece is bolted for the seating, and is firmly held in position with a strap, fitted to some convenient part of the boiler; the pipe having an expansion joint with stuffing box and gland at the bottom, for taking the horizontal copper pipe passing along to the cylinders; thus it can freely expand and contract without straining it. The valve has a jointed rod passing downwards to a lever, which is keyed on the shaft which passes through the stuffing box on the end plate of the fire-box shell, the other end being supported with a boss cast on the vertical pipe, and which is bored out for its reception, a plain handle with quadrant and set screw or pin, for holding the valve up, being placed at the outer end of the shaft.

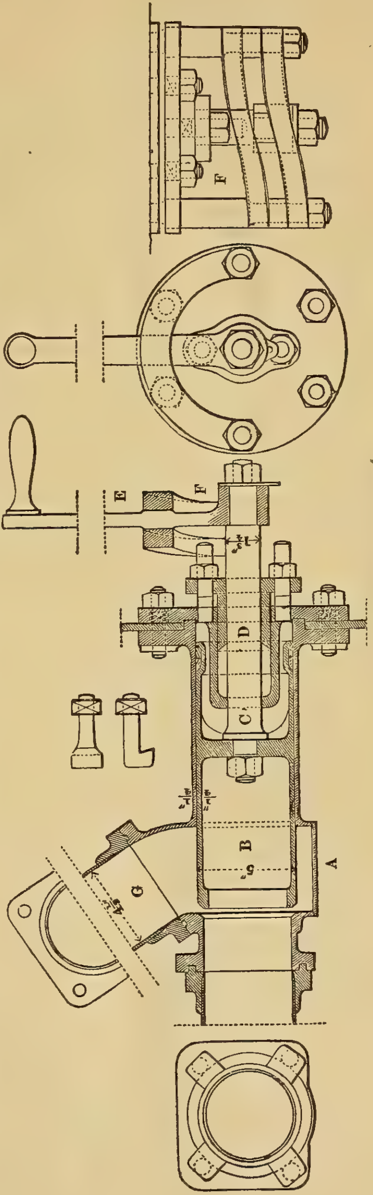


Fig. 417.—Circular Regulator.

A, Valve box. B, Circular valve. C, Rod. D, Stuffing box. E, Regulator handle. F, Spiral segment. G, Steam pipe.

The steam pipes in the smoke box when made of copper are about $\frac{3}{16}$ inch in thickness; this is to allow for the wear by the action of the cinders. Sometimes cast-iron pipes are substituted, and should be at least $\frac{5}{8}$ inch in thickness, but copper pipes are preferable, as the cast iron is liable to deteriorate from corrosion. As the steam pipes in the smoke box are made of a bent form, it is not necessary to provide any expansion joints; they are simply bolted to a cast-iron branch fitted to the end of the tube plate, while at the bottom end they are bolted to flanges cast on the cylinder branch pieces.

The *blast pipe* is generally made of cast iron, although sometimes copper is used. It tapers in a gradual manner from the bottom upwards. The best arrangement for inside cylinders is one central pipe taking both of the cylinders; it is usual to make the nozzle of copper, which is secured to the top of the cast-iron pipe with set screws. The blast orifice should be quite smooth and true; sometimes a brass ring is brazed on the copper piece, or in some a flange is secured to the top of the pipe, and which is accurately bored out, so that there is a true and smooth surface for the exit of the steam. It is of the utmost importance that the blast orifice should be exactly in the centre of the chimney, blowing the waste steam in a true vertical line; otherwise, should the waste steam be blown against one side of the chimney it tends to impair the exhaust, or partial vacuum, formed in the smoke box, and consequently the draught through the boiler is slightly affected.

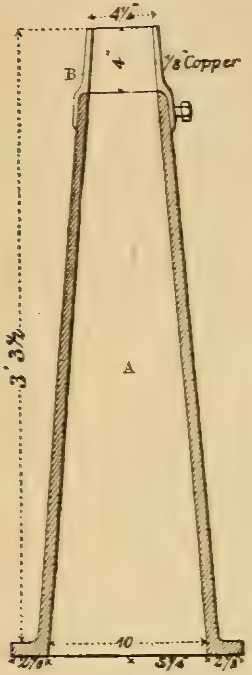


Fig. 418.—Blast Pipe.

A, Blast pipe. B, Copper nozzle.

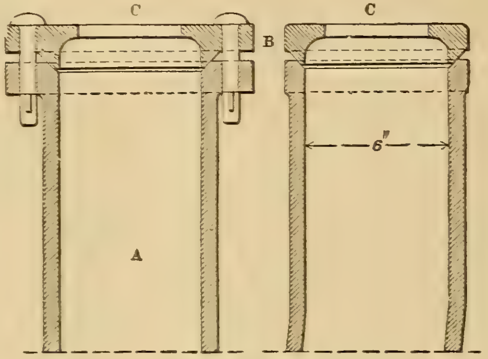


Fig. 419.—Blast-pipe Orifice.

A, Blast pipe. B, Flange. C, Hole bored out.

With outside-cylinder arrangements there is a blast pipe fitted to each cylinder, meeting a branch piece at the top, which should be quite straight for a short length vertically, otherwise the waste steam from the bent pipes, curved to the sides of the smoke box, will strike alternately on each side of the chimney, thus tending to impair the draught through the fire grate and tubes placed in the body of the boiler. In modern practice the blast orifice is a considerable distance from the crown of the smoke box, just above the top row of tubes: this has been found, with a wide spreading funnel, or even with the usual taper, to create a superior draught with a wider blast orifice, and is now commonly adopted.

There are generally two *safety valves* provided, placed on the top of the steam dome, or on the manhole door situated on the top of the fire-box shell. In the latter case a third valve may be fitted on the top of the steam dome on the boiler, which is loaded directly by means of a spiral spring placed on the top of the valve, having two screwed columns or long stud bolts and nuts, taking a cross bar which is placed on the top of the spring, and then screwed down with the nuts until a certain and constant pressure on the

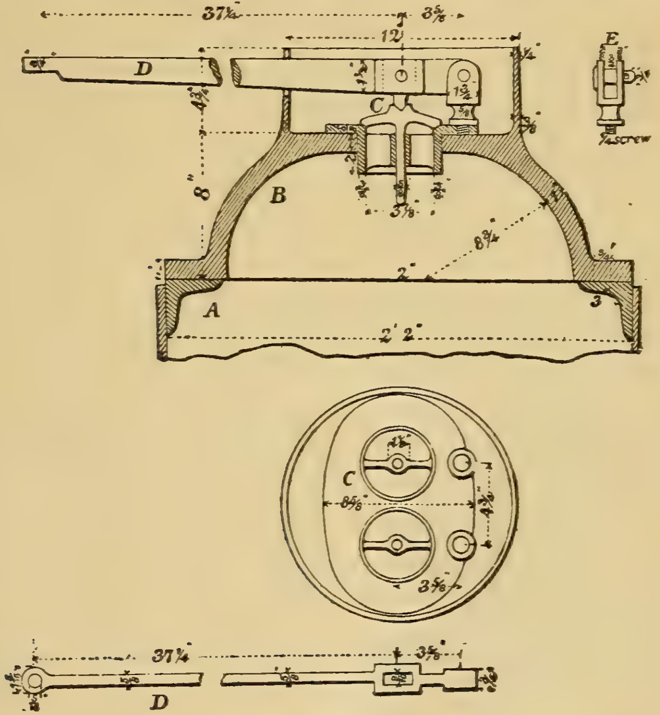


Fig. 420.—Safety Valves.

A, Dome. B, Cast-iron top for dome. C, Safety valves and seats. D, Lever. E, Stud for lever.

valves is obtained to resist the internal steam pressure. The other safety valves are fitted with a lever and spring, which can be regulated with a thumb screw to any pressure within range of the Salter balance fitted with a helical spring, graduated to indicate 1 lb., 5 lbs., &c., intervals of pressure; the spring is so adjusted that a weight of 1 lb. attached to the balance would move the index to 1 lb. as marked by the scale, the lever being so proportioned to suit the area of the valve that a pressure of 1 lb. indicated by the scale gives 1 lb. per square inch on the valve. The valves formerly much used were conical spindle ones, with the bearing surface bevelled to an angle of 30°. Some makers round the point of contact on the valve, and although they are not so liable to gag in locomotive practice owing to their being frequently opened, still they are objectionable, as they do not give so free a passage for the steam as the flat-disc valve or the spherical one. The former has been arranged in a variety of ways; one good form being an inverted cone with a flange at the base which bears on the seating, the two surfaces being accurately turned, and then ground together to make them perfectly steam tight, the thrust pin on the lever bearing on the internal apex of the cone, the valve being cast hollow for that purpose. The annular flat-surface valve (Fig. 422) differs materially from the ordinary ones and from the foregoing, inasmuch as the steam, besides escaping round the valve when raised, escapes also through an annular aperture cast in the valve, thus possessing the advantage of two edges, instead of one edge as in the ordinary disc valves, for the steam to escape by, and consequently with a given diameter, and the lift of the valves of both kinds being equal, the annular valve will pass about double the quantity of steam, while the area exposed to the steam pressure in the boiler being much less, the holding-down load is reduced in proportion. The spindle is hollowed out for the reception of the thrust pin, as in the previous

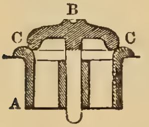


Fig. 421.—Safety Valve with point of contact rounded.—A, Valve seat. B, Valve. C C, Part rounded.

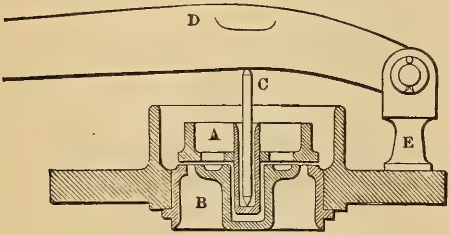


Fig. 422.—Annular Safety Valve.
A, Valve. B, Seat for valve. C, Spindle. D. Lever. E, Stud for lever.

example, and in both examples the valves are frictionless in the act of lifting, which is the main thing to be studied in safety-valve arrangements. To carry this more fully into effect the ball safety valve has been designed, fitted with a lever and spring balance. All the bearings are of the ball-and-socket description; thus freedom of action is secured, while the tendency to corrode or stick is rendered nil. The ball is generally cast in gun metal, and the seating of brass. This valve has the advantage that the ball may be turned into any position to suit the wear.

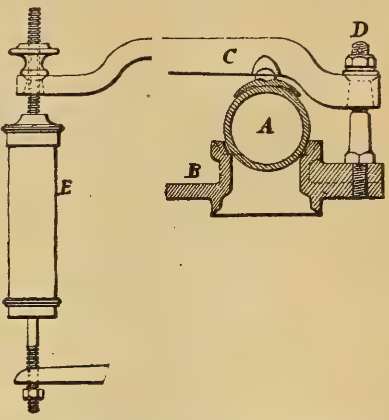


Fig. 423.—Ball Safety Valve with Lever and Balance.

A, Ball valve. B, Seat for valve. C, Lever. D, Stud. E, Salter spring balance.

Various forms of direct spring-loaded valves have been successfully adopted; one form consisting of a large plate 12 inches in diameter, loaded with a number of volute springs, arranged uniformly around the centre of the valve, the bearing surface of the springs resting in cups on the valve, while the large flat surface at the top bearing on the covering plate renders the action quite true, and as there are no spindles connected to the outside springs there is no liability to jam. So large a valve is not really required for the locomotive boiler; but the principle can be carried out with one small valve having a central volute spring.

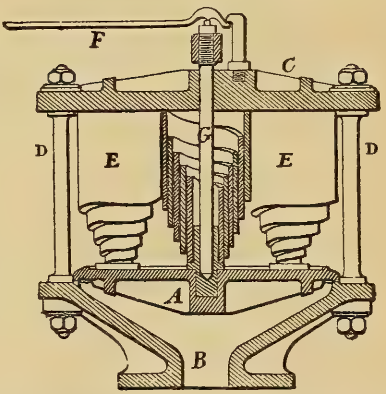
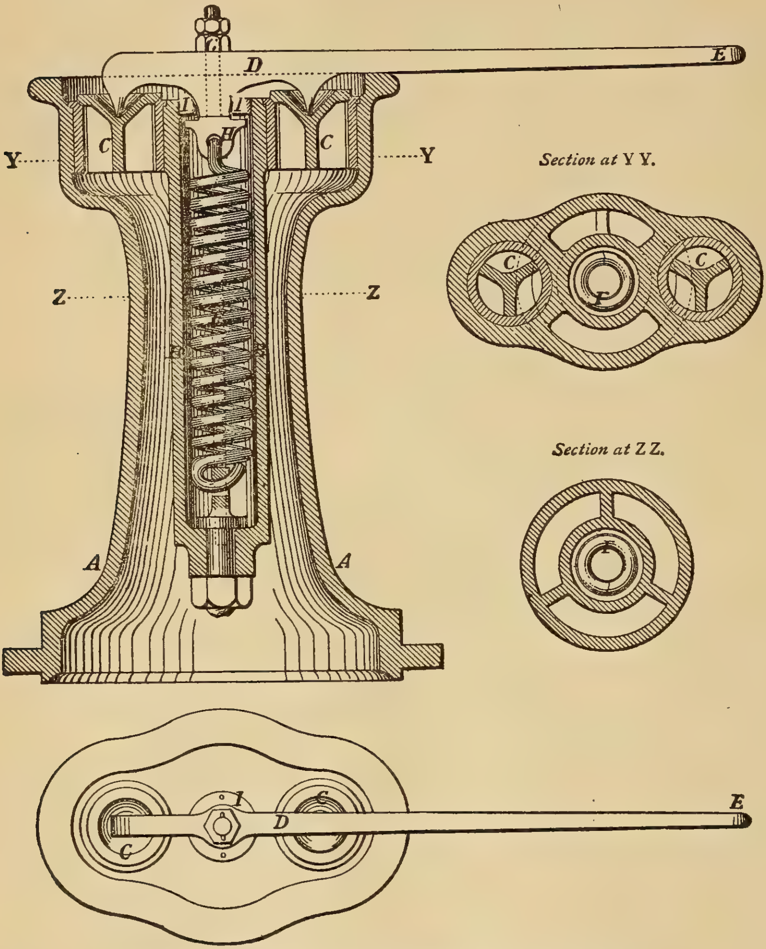


Fig. 424.—Safety Valve directly loaded with Springs.

A, Plate valve. B, Seat for valve. C, Covering plate. D D, Screw studs for adjusting the springs. E E, Volute springs. F, Lever. G, Spindle.

Although there may be a difference of opinion as to the proportion which the working pressure of a boiler should bear to its absolute strength, it will doubtless be admitted that the greater the certainty of a safety valve opening at the required pressure, and the greater its range of lift under a given excess of pressure, the less will be the excess of strength required. If a perfect safety valve could be made—that is, one which will absolutely prevent the boiler to which it was applied from being subjected to a higher pressure than that to which the valve was adjusted—it would of course be conducive


Section at Y Y.

Section at Z Z.

Fig. 425.—Pillar with Safety Valves and Central Spiral Spring.

A A, Pillar. B B, Central part for spring. C C, Valves. D, Crosshead. E, Hand lever. F, Spring. G, Screwed spindle and nuts. H, Shackle. I I, Plate screwed into the top of pillar.

in a high degree both to the safety and durability of such boiler. The following arrangement goes far to meet the requirements, the only friction while lifting being from the valves themselves, and which may be entirely avoided by the substitution of spherical valves. A pillar consisting of one casting, which answers the purpose of the manhole door, is bored out at the top for the reception of the valve seatings, two in number. The valves are loaded by the spring placed in the central box, which is secured to a crosshead taking both of the valves, the crosshead being elongated to serve as a handle, to enable the driver or engineman to ascertain the working condition of the valves. The spring is made of sufficient strength to resist the pressure on both valves, and is adjusted by the nut on the top of the crosshead. The shoulder on the underside of the crosshead should be drawn hard up when the maximum load is put upon the valve. To prevent the valves being blown away in the event of the spring breaking, the shackle fitted to the lower part of the crosshead for taking the spring has two projections formed on it, projecting beyond the slot in the cap which is screwed into the top of the pillars. The valves, being equally loaded and of equal size, will be simultaneously lifted with the cross bar when the steam pressure exceeds the proper limit, and the spring will be elongated through a range equal to the lift of the valves, and no more; so that, except when the engineman is testing the action of the valves, there is no movement in the joints of the apparatus, and therefore no friction. A spring of ⅝-inch round steel, and about seven coils, is sufficiently strong to load two 3-inch valves to 80 lbs. pressure per square inch, and in order to load them to this extent the spring will have to be stretched about 1¾ inch, or ·218 inch for each successive increase of 10 lbs. pressure per square inch. In the example we have delineated the spring is of smaller diameter than the above, and consequently lengthened to make up for the reduction in diameter. Another arrangement shows the application of the volute spring, which is placed in a shallow well in the manhole cover and adjusted by four nuts, which force down a cover plate placed on the top of the spring, and so compress the spring until the requisite pressure is obtained. Packings are then fitted between the cover plate and the manhole lid to prevent any extra pressure being applied. It is evident that, under any form, the valves cannot be easily tampered with; and a brass funnel may be placed over them in the ordinary way. Several of these valves have been at work, proving highly satisfactory. They were found to be very sensitive, having such freedom of action as to get into a state of vibration, producing in some cases a musical note when at the point of blowing off; and they allow the steam to blow off more freely than other safety valves under a given excess of pressure. The arrangement of the two valves under one lever is not new, but the object in the above arrangement is to increase the lift of the valves, making it equal to the full extension of the spring, giving great freedom for the discharge of the steam, and preventing it rising above a dangerous pressure, and also to dispense with the spring balance. The point of attachment of the spring is rather below the level of the points bearing on the valves, so that in the event of one valve lifting before the other it is overloaded, the other being proportionately relieved, thus tending to secure their simultaneous action. There is no scale attached; the spring is adjusted originally to the maximum pressure intended by measuring the amount of elongation or compression under a given load, and by adjusting the screw to within 2 or 3 per cent. of the compression or elongation produced by the desired pressure. The valves are tested previous to being used, by comparing them with a pressure gauge attached to the boiler.

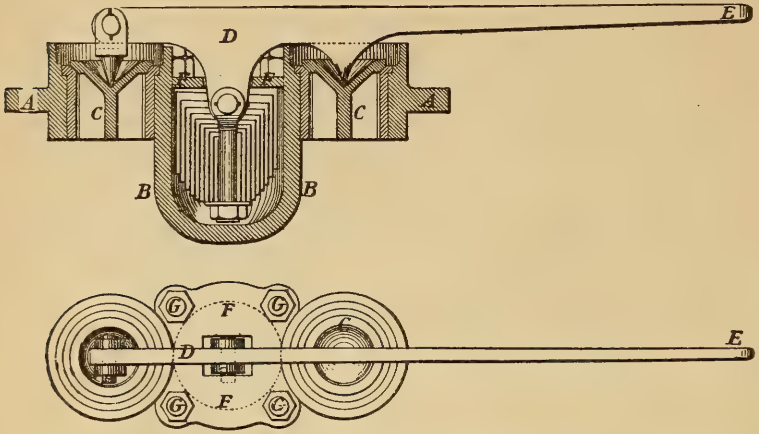


Fig. 426.—Safety-valve Box with Central Volute Spring.

A A, Valve seat. B B, Centre part for spring. C C, Valves. D, Crosshead. E, Hand lever.
F F, Plate with bolts for holding down the spring.

The *waste-steam funnel* for covering the safety valves is made of thin brass, and is kept highly polished, giving the engine a smart appearance. It takes in both of the valves, delivering the waste steam at sufficient height so as not to interfere with the free vision of the driver. It is made tapering from the bottom upwards, ending in a plain circular moulding at the top, and spreading out at the bottom with bold curves to suit the curve of the fire box; at the top it is suddenly contracted with a funnel-shaped piece brazed thereto, having a hole of only sufficient diameter for the escape of the steam, a plate being brazed at the top embracing the outlet and extreme diameter of the moulding. All these funnels should be as plain as possible, as they are more easily kept clean, no corners being left with beads or small mouldings for dust to collect. They serve the purpose of protecting the safety valves from injury, and when the valves are loaded directly, and so covered, they are not easily tampered with.

The *covering dome* for the steam chest is generally of cast iron, spherical at the top, and when the safety valves are fitted on the top of the steam chest a curved outlet is formed on the dome for the escape of the steam. The bottom is finished in a similar way as the waste steam funnel, with bold curves embracing the body of the boiler, to which it is securely bolted with stud bolts and nuts. Sometimes these covering domes are made of brass, kept highly polished, and present a very handsome appearance; but we consider it preferable to have them made of cast iron, and properly painted, as the large brass surface is difficult to clean, and in the act of doing so the paint on the body of the boiler gets rubbed off, and soon becomes shabby. In like manner we consider all the mouldings on the body of the boiler should simply be painted, for when they are highly polished extreme care must be taken when cleaning is going on; in fact a locomotive should be cleaned down very carefully, for when the paint gets rubbed off, like an ill-groomed horse, it is not at all nice looking. The *steam horse* well kept is most pleasing to the eye, and is certainly, as a whole, the greatest triumph in steam machinery.

The *water gauge* placed on the outside of the fire-box shell is for showing the height of water above the crown of the fire box and tubes. It consists of a glass tube ¼ inch internal diameter and ⅛ inch in thickness; it should be properly annealed to resist the sudden and varying temperature it is subjected to. The ends of the tube are made steam tight, with hemp and a screwed gland; the stuffing box at the top end allows of the expansion of the glass tube, while the tube rests on the bottom one. By this means the glass tube passes through the hole at the bottom of the stuffing box at the top end, and thus freely slides with the expansion and contraction without compressing the hemp packing.

The connections simply consist of a branch piece at the top and bottom of the glass tube, having a flange for bolting to the flat part of the fire-box shell, fitted with a plug tap between the glass and

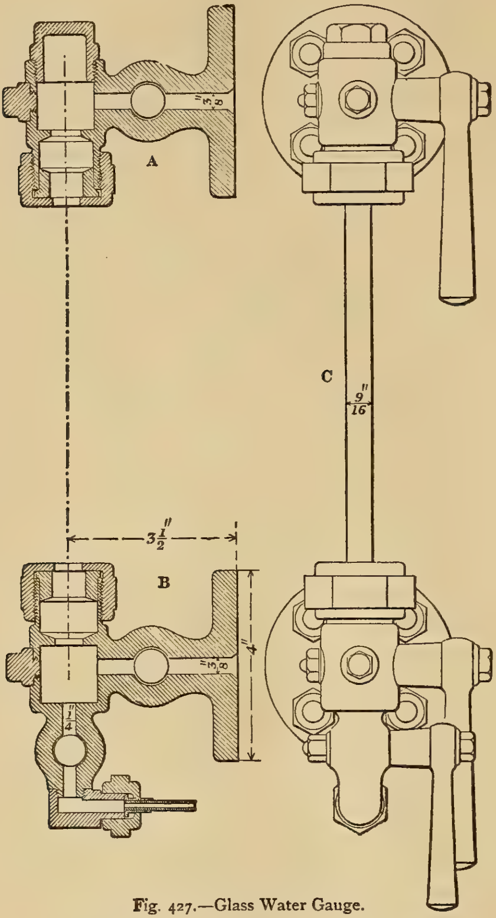


Fig. 427.—Glass Water Gauge.
A, Top piece. B, Bottom piece. C, Glass tube.

the boiler, with a screwed cap for putting in a fresh tube, and a screwed plug in a line with the passage through the plug tap. By this means a rod can be passed through to clear away any deposit. The packing glands for the glass tube are provided with a loose ring, which is screwed down over the packing with a screwed gland. The plug taps are required in the event of the glass tube becoming fractured, thus providing a means of preventing a rush of steam, as they can be instantly shut when required. There is a plug tap at the bottom, in a line with the glass tube; this is the test tap for showing if all the passages are in free communication with the steam and water space, so necessary for truthfully working of the apparatus. The range of the index in connection with the tube varies from 9 to 10 inches, the general working height of the water above the crown of the fire box being from 5 to 6 inches. Three additional plug taps are screwed into the fire-box shell; the bottom one should be placed 3 inches above the crown of the fire box, while the top one should be tapped in 6 inches above it. These plug taps are used in the event of the glass tube breaking. An experienced driver can at once tell by opening them whether there is enough water over the crown of the fire box. When the gauge is fitted to the side of the fire-box shell it is connected with a brass pipe, having distance pieces of cast iron fitted to the curve of the box, the three additional test taps being tapped into the brass pipe, having the main gauge connection at the top and bottom of the pipe. This pipe is closed at the ends with screwed plugs, which can be removed for clearing it from deposit.

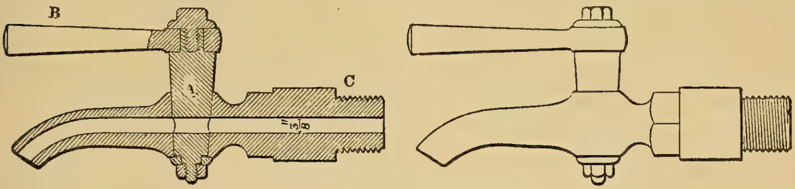


Fig. 428.—Water Gauge. Plug Taps.
A, Plug tap. B, Handle. C, Screwed part.

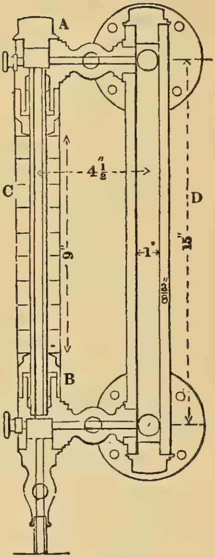


Fig. 429.—Glass Water Gauge and Connections.—A, Top part. B, Bottom part. C, Glass tube and index plate. D, Brass pipe.

The *pressure gauge* indicates the difference between the pressure of the steam in the boiler and the atmospheric pressure. One form consists of a curved flattened tube, into which the steam is admitted, and which becomes more or less curved according as the pressure is less or greater. For it is a law of nature, that bent tubes under internal pressure have always a tendency to become straight. The tube has an oval section, is fixed at one end, and in communication with the steam in the boiler; the other end is filled up, and has a connecting rod attached to a lever, with toothed quadrant and pinion, the pinion spindle carrying the index handle, which revolves in the centre of a disc plate, marked round the circumference to indicate the pressure in pounds per square inch, the whole being inclosed in a suitable box. It is fitted to the cab, or weather protecting plate, having a U-shaped wrought-iron pipe connection. Water lodging in the bend, or oil poured in, prevents such delicate instruments from becoming overheated with the steam so necessary for their proper action.

The *steam whistle* is placed at the back of the outside fire box, or on the manhole door on the top of the box. It consists of a plug tap screwed into the door, which is in connection with an annular chamber, the steam escaping through a narrow annular aperture, blowing against the edge of the bell, which is generally from 3 to 3½ inches in diameter and 2½ inches in depth. It is usually cast in hard brass, this size producing the musical note D natural, which is sounded with about 80 lbs. of steam pressure, higher pressures giving a much shriller sound; and as the fulness of tone is affected by the pressure, the driver must open the aperture cautiously, or wire-draw the steam through the tap to give the full note when the pressure exceeds 80 lbs. When the handle is not within reach of the driver, a lever is substituted, with a connecting rod and handle passing through the weather plate, fitted to the back of the fire box.

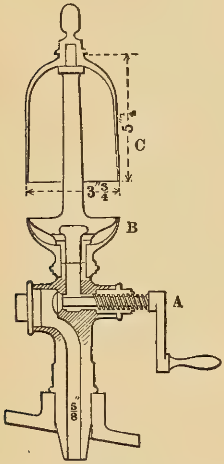


Fig. 430.—Guard's Steam Whistle.

A, Valve with handle. B, Annular chamber. C, Bell.

The *guard's whistle* is of the same construction, but the bell is made larger, about 3¾ to 4 inches in diameter and about 5 inches in depth. This gives a much lower note, which is easily distinguished from the ordinary whistle. Instead of the plug tap, a valve having a screwed spindle is sometimes used, which is worked with a suitable handle, or lever and connecting rod. This plan has the advantage of being better able to adjust the volume of steam, so as to produce a clear note, according to the steam pressure in the boiler.

The *blow-off plug tap* or valve fitted to the bottom of the fire-box shell, to blow off foul water and sediment, is usually from 1½ to 2 inches in diameter. It consists of a solid plug tap, or a hollow tap inverted is used, with a rod and handle fitted to the small end of the plug, worked directly from the engine platform. Screw plugs for sludge apertures at the corners of the fire box are 2 inches in diameter, screwed into a plate having a boss forged thereon. The plugs should be made of hard brass to prevent corrosion, and should have a strong square part cast on for taking the strain of the screw key. When fitted to the sides of the shell of the fire box, on a level with the crown of the inside fire box, so that a water-hose may be inserted, washing away any sediment collecting, a good form of sludge door is simply a brass flanged pipe piece (Fig. 432), having a screwed cap, with square piece cast on for applying a screw key, as in a water hydrant. This plan has a free opening, the screw being cast on the outside, and as such the screw is protected from injury from the tools used in clearing the deposit which lodges at the bottom of the fire-box water space.

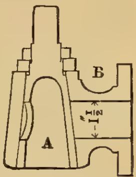


Fig. 431.—Blow off, Hollow Tap.—A, Hollow-tap valve. B, Seat for tap.

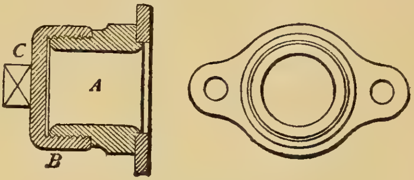


Fig. 432.—Sludge Hole.
A, Sludge pipe. B, Screwed cap. C, Square part for unscrewing by.

Heating plug valves are fitted to the shell of the fire box, being located above the water line in the boiler. They are used for blowing the steam into the tender or tank for heating the water, but only when the engine is standing, or when there is a surplus of steam in the boiler that would otherwise blow to waste.

The pipe fitted to the heating-plug valves for leading the steam into one or both of the suction pipes for the pumps is of copper, 1 inch in diameter, and is connected with couplings to the valve and suction pipe, the pipe having a slight bend to facilitate making the metallic joints, which are screwed firmly together. These heating cocks and pipes are only fitted when ordinary pumps are used for forcing the water into the boiler, but when an injector is adopted they are dispensed with.

The *lubricating plug tap* for the steam-regulating valve, slide valve, and cylinder, is fitted in mostly all instances to the top of the smoke box, with a pipe connection to the regulating valve, the oil flowing from thence into the cylinder, or otherwise carried along with the particles of steam. It simply consists of a hollow conical plug, into which oil or melted tallow is poured through a hole in the shell. The plug has a handle connected to it in the usual way, so when the valve is filled it is turned half round, until the opening comes opposite the pipe, when the oil gravitates into the regulating valve chest, and thence into the cylinder.

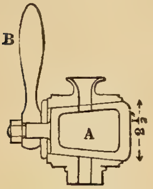


Fig. 433.—Lubricating Plug Tap for Steam Valves, &c.

A, Hollow plug valve.
B, Handle.

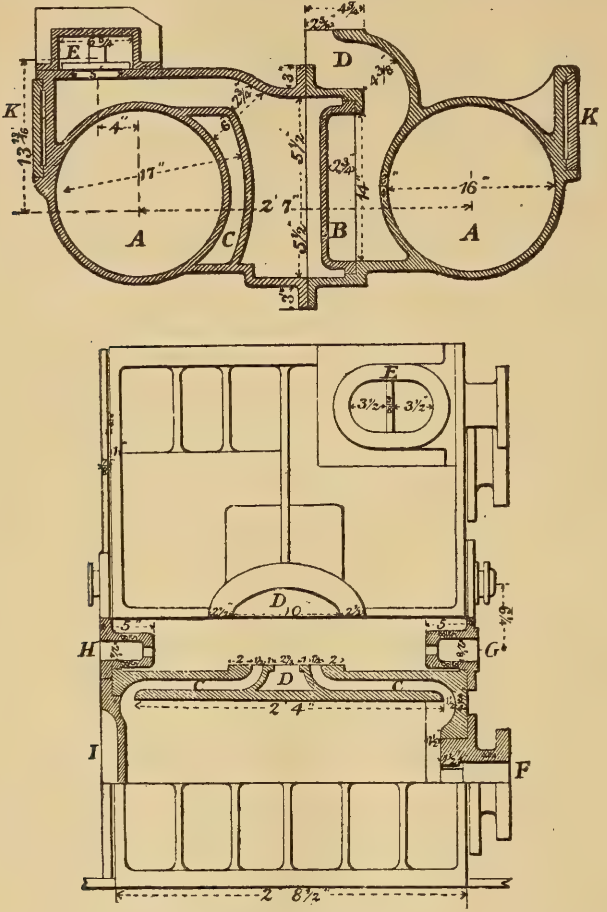
A *hand rail* of iron, or iron sheathed with brass, is fitted to the body of the boiler, secured with stud eyes screwed into bosses forged on plates, which are rivetted to the shell. This hand rail should likewise be fitted across the front end of the smoke box, to insure safety when passing along the framing while the engine is in motion.

A *stud* for the forward lamp is rivetted to the top part of the front of the smoke box; these lamps have a powerful light, and are aided with a reflector, so as to show for a considerable distance whether the line of railway is free from obstruction.

CONSTRUCTION OF THE ENGINE, &c.

Cylinders, covers, and glands.—The *cylinders*, whether placed inside of the smoke box, or, as in more modern practice, between the frames, and in a variety of examples outside of the frames, are arranged horizontally in some engines, and inclined in others. With the inside arrangement the inclination given to the cylinders and machinery is simply to obtain the necessary clearance above the axle of the leading wheels, when of the same diameter as the driving wheels; while there is no such necessity when the cylinders are placed outside of the framing, the angle given to the cylinders and machinery being a matter of opinion with the various designers. As regards the inclination to be adopted in connection with the general arrangement—when the leading wheel axle is fitted with outside bearings, with springs on the top of the axle box, the inclination must be greater, so as to effect the necessary clearance above the springs; while in those arrangements having only inside bearings for the axle of the leading wheels, the cylinders are generally arranged horizontally, by which the pattern-making becomes much more easily executed, while there is evidently a saving in fitting up, and the weight is kept lower down, with the advantage of direct action in a horizontal line through the framing. The cylinders are of hard cast iron, and in some instances wrought iron has been employed, but it is evident this material is very costly. Toughened cast iron has been used with advantage, being a mixture of cast and wrought iron.

In former practice the cylinders were arranged inside of the smoke box, holes being cut in the prolongation of the tube plate, as well as in the front plate of the smoke box. The arrangement was very compact, but the labour of fitting up was expensive, while the disadvantage of attaching the machinery to the boiler soon became evident from the expansion of the latter, causing a severe strain to those parts rigidly held by the boiler and connected to the framing. To overcome these difficulties the framing is arranged to take the cylinders between the two horizontal plates running the entire length of the engine, thus in a great measure keeping them independent of the boiler. The cylinders are cast open at the ends in some, while in others the back end is partially closed, greatly strengthening the casting, only leaving an aperture of sufficient size for the boring bar to pass through. All the passages or ports and valve casings are cast along with the cylinder, as likewise the side brackets, which are well ribbed in the casting, and which form a strong junction between the cylinder and framing. The weight of the cylinders rests on the top of the frames, a projection being left on the casting for that purpose; thus the cylinders can be fitted to the framing quite independent from the boiler, which may be in the process of manufacture. The cylinders are joined together on the centre line, with flanges at the top and bottom running the entire length, the exhaust passage being placed at the top immediately over the exhaust ports. In this arrangement there are valve doors fitted to the front and back, the latter having stuffing boxes and glands for the valve rods, while the former is fitted with stuffing boxes and glands to take the ends of the valve rods acting as guides in maintaining a true line of action. In other arrangements there is only one door at the front, while at the back the stuffing box for the valve rod is cast along with the



Figs. 434, 435.—Cylinders.

A A, Cylinders. B, Valve. C C, Steam ports. D D, Exhaust passages. E, Regulator and chest. F, Back cover. G, Stuffing box for the valve rod. H, Guide piece for the valve rod. I, Front cover. K K, Main frames.

cylinder. The front cylinder cover is of the usual construction, and is generally bolted to the cylinder flanges with stud bolts and nuts; while the back cover is of smaller size, fitted with stuffing boxes, bottom brass, and gland, and secured to the cylinder in like manner. The generality of back covers have also projections cast on for taking the motion bars, as shown by Fig. 436. There is one regulator common to both cylinders, having the passages cast along with one of the cylinders, while the other one is left plain, the valve casing being a separate casting bolted to the cylinder. In some examples with inside cylinders the main steam valves are placed on the top, with separate valve-casing covers for each cylinder. Although for all arrangements, whether horizontal or inclined, the framing forms the chief mode of attachment for the cylinders, sometimes they are likewise let into the tube plate and front plate of the smoke box, the sides of the smoke box ending on the top of the framing.

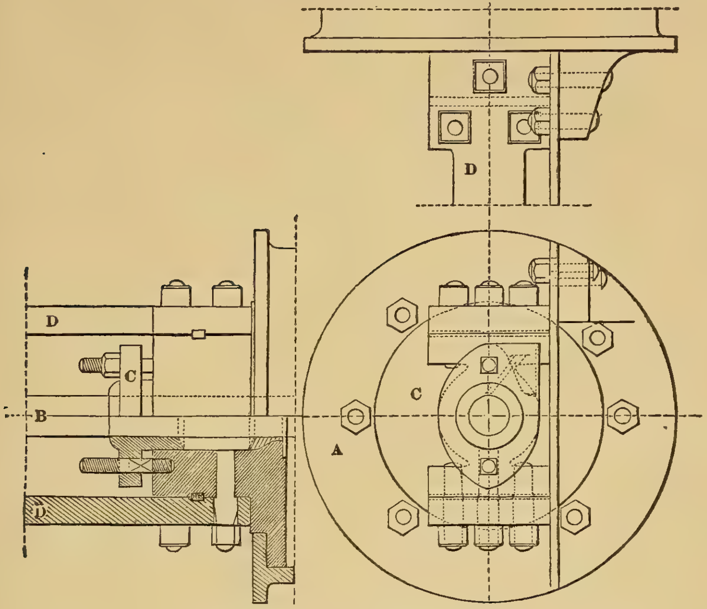


Fig. 436.—Back Cover for Outside Cylinder.
A, Cover. B, Piston rod. C, Stuffing box and gland. D D, Motion bars.

For outside-cylinder arrangements the framing affords the sole means of attachment. When small leading wheels are adopted, and in some cases with large wheels of the same diameter as the drivers, the valve casing is placed on the side, towards the centre line of the engine, and passes through an aperture formed on the framing, to which it is securely fastened with bolts and nuts passing through flanges cast on the cylinder. The centre line of the valve spindle in the above example is in a line parallel with the cylinder, but if large leading wheels are adopted it is necessary to incline the rod to obtain the necessary clearance above the axle. In all these examples the steam ports are much longer than in ordinary arrangements, but at the same time some are shorter than others, provision being made by the slide valve so as to make them as short as practicable. To reduce them to the usual length they may be, and are arranged on the top of the cylinder; but this plan necessitates an indirect motion for the valve gearing—that is to say, when the valve is placed horizontally; but in many arrangements the valve is inclined, while the valve gearing is direct, although not in the same horizontal line as the cylinder.

The valve casing is sometimes cast along with the cylinder, having a door conveniently arranged with a view to its being easily removed; while in other examples the casing is a separate casting, bolted to the cylinder with long stud bolts, the same bolts taking the cover. The cylinder covers at the front end are sometimes recessed, having an L section of piston to suit, and which passes into the recess, while others are recessed at both ends, having a T section given to the piston. By this means the cylinders and adjuncts can be made a little shorter, which may be considered by some an advantage, but the main advantage consists in the piston, which is greatly reduced in weight by using any of the above sections.

The inside length of the cylinder, between the cover and the back end, is equal to the length of the stroke, to which is added the thickness of the body of the piston, and the clearance at each end, which is usually ¼ inch, and in some ⅜ inch is allowed. This is necessary to allow for the variations in the length of the connecting rod, due to the wear and other causes affecting the position of the piston in the cylinder: in the event of the water in the boiler priming over also, some space must be left to get rid of it, otherwise the ends of the cylinder would be unduly strained.

The steam ports are of a rectangular form, cut square in at the corners in most examples, while some are slightly rounded at the corners; the face generally projects above the metal of the port ½ inch, to keep the valve clear of the metal on port, as likewise to allow for wear. The steam ports run partly into the covers at both ends; by this means the piston does not travel past the edge of the port too much at the end of the stroke.

All the joints are metallic; they are planed all over and then scraped, to make them perfectly steam tight, and when finally put together receive only a thin coating of red lead prior to tightening up the bolts.

For valve chests exposed to the action of the smoke and dust collecting in the smoke box, brass nuts of considerable depth are to be preferred, the nuts so formed as to inclose the point of the bolts. Those nuts having no tendency to corrode are preferable to iron ones, as they do not strain the bolts when taken off, being very easily unscrewed.

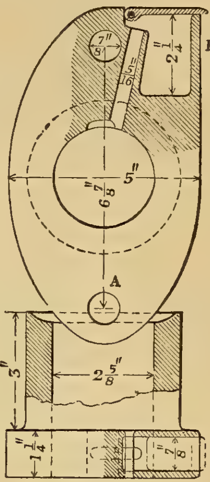


Fig. 437.—Gland for Stuffing Box of Piston Rod.

A, Gland. B, Oil cup.

In order thoroughly to provide for the lubrication of the piston and valve rods, cups are sometimes formed in the brass glands, fitted with a hinged cover. The stuffing box has the usual brass lining piece at the bottom; both it and the gland are hollowed out at the end bearing on the packing: thus when the packing is pressed up it is forced out against the rod. Two stud bolts and nuts are required for each gland. The valve rod passes through the front of the steam chest, and is guided by means of a stuffing box and gland, and in some instances works in a brass tube, closed at the end, the tube being bolted to the steam chest. With this arrangement there should be a small hole cut where the rod bears on the neck of the tube, so as to allow water accumulating to be ejected, which would otherwise eventually rupture the tube.

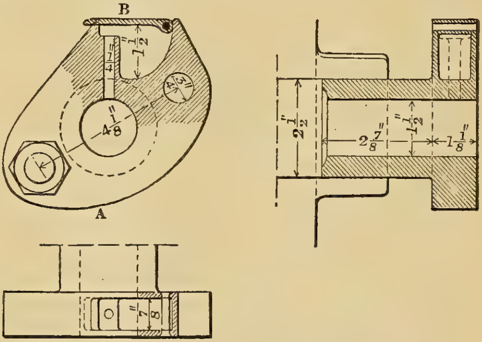


Fig. 438.—Gland for Stuffing Box of Valve Rod.

A, Gland. B, Oil cup.

A *plug tap* is fitted to the bottom of the cylinders at the front and back, placed at the lowest part, so that any water accumulating may be run off. Their bore is usually $\frac{7}{16}$ or ½ inch in diameter; they are fitted with spindles and levers, with a rod passing along to the starting platform. These taps are generally left open for a considerable time after the engine is started;

the cylinders being of course cold, condensation will take place, and the water accumulating is forcibly ejected along with the steam. As a considerable waste of steam takes place, the bore of the taps is made small to prevent excessive loss.

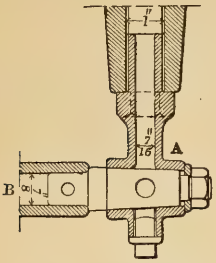


Fig. 439.—Cylinder Plug Tap.

A, Plug tap. B, Rod.

A plug tap is likewise fitted to the lowest point of the valve casing, which should be opened prior to starting the engine, or when the water from the boiler primes over, thus tending to keep the water out of the cylinders. The engine driver can easily detect when priming is going on while the engine is running, and should always have the means of opening the plug tap from the platform, in a similar way as the small taps fitted to the bottom of the cylinders.

Grease cups should be fitted to each top corner of the cylinder. They are provided with a plug tap at the bottom, which is screwed into a hole tapped in the cylinder. This plug tap carries a close cup, fitted with another plug tap at the top, through which the melted tallow can be run into the cup while the engine is in motion, for the lubrication of the piston and cylinder, the tap for the escape of water in the cylinder being shut. There is another grease cup for lubricating the regulating valve, steam valve, and piston, which is fitted to the top of the smoke box or side of the smoke box, as already described.

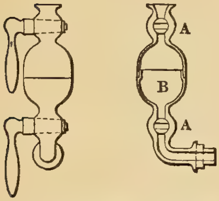


Fig. 440.—Grease Plug Tap.

A A, Plug taps. B, Cup.

The *main slide valve* is generally of cast iron. Sometimes brass valves have been adopted, the cylinder faces wearing better with such valves. But when cast-iron valves are used, placed on edge, they are found very efficient. The valves are of the short D description; the valve rod or spindle for working them in connection with the valve gear has a strap forged on, embracing the whole of the valve, leaving it free to move towards and from the face of the cylinder, the valve being held to the face with a light steel spring, secured with stud bolts and nuts to the valve rod. Sometimes the strap embracing the valve is not in a line with the rod, but is bent in the forging to suit any peculiarity in the arrangement of the valve gear. It is an object with high-pressure steam to relieve the valve from the pressure; with this in view rings properly packed have been fitted to the back of the valve, thus placing, as it were, the valves in equilibrium, or relieving them greatly from the pressure, reducing the wear and tear, and making them much more easily handled.

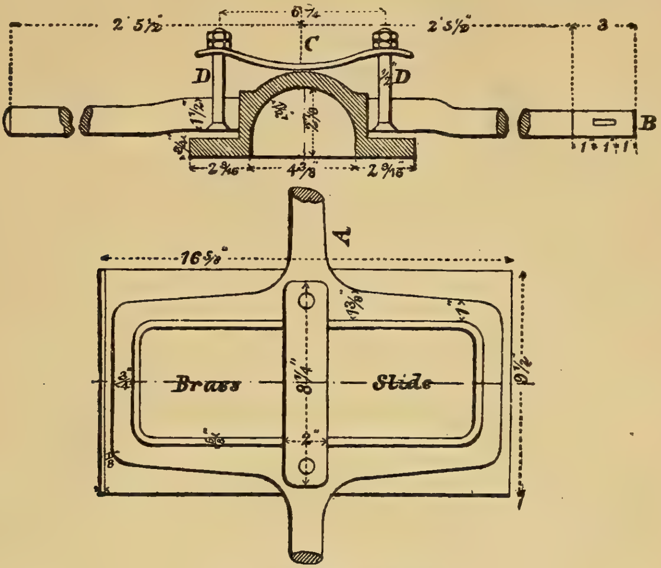
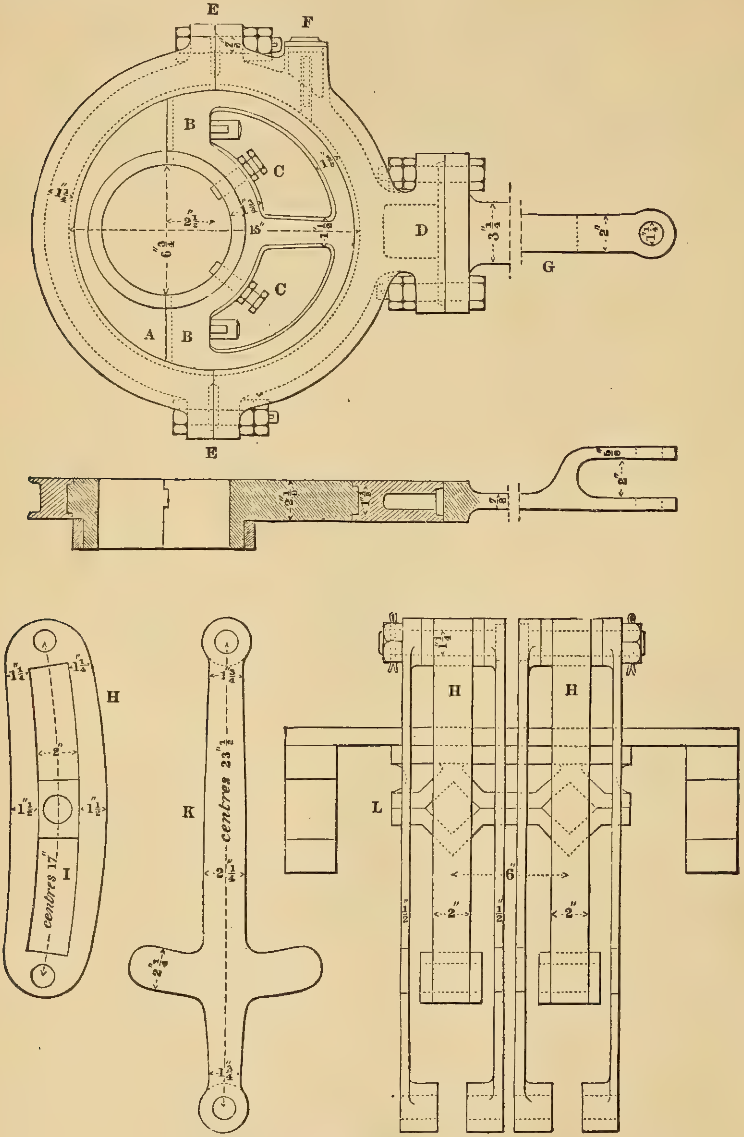


Fig. 441.—Slide Valve and Rod.

A, Slide valve. B, Valve rod. C, Spring. D D, Stud bolts.

A very general plan consists of a separate disc plate and packing ring (working steam tight against a central plate in the steam chest), which is secured to the back of the slide valve: thus the pressure of the steam, acting as it were in opposite directions, tends to relieve the valve from pressure. At the same time, the arrangement allows for the wear of the valve.

Another plan well suited for the locomotive engine consists in casting a short cylinder along with the valve, and situated behind it, which is accurately bored out for the reception of a thin packing ring. This ring is turned slightly larger, and is cut through at one part, and sprung in the cylinder: thus it forms as it were a piston ring, fitting steam tight into the cylinder, while at the same time the thin edge is pressed up against a fixed plate, with steel springs placed between the ring and the valve. A round pin is let into the valve, a hole being bored in the spring ring to receive it, to prevent the ring turning round. A hoop is forged on the valve rod for taking the cylindrical part of the valve, thus forming a loose connection between the valve and the rod.



Figs. 442, 443.—Eccentric, Expansive Link, &c.

A, Eccentric. B B, Pins and cotters. C C, Set screws. D, Strap. E E, Snugs and bolts. F, Oil cup. G, Rod. H H, Links. I, Slide Block. K, Lifting rod. L, Guides for valve spindles.

Valve motion.—Double eccentrics and link gear are generally used for giving motion to the steam valves, the parts pertaining to these consist of sheaves, straps, rods, links, sliding blocks, lifting links, guide bar and block, weigh bar and lifting arms, with balance arms, and reversing rod, lever, and quadrant.

The eccentrics are of cast iron, made in two pieces secured together with pins and cotters, having a groove and feather for preventing any movement sideways. The eccentrics are held in position on the shaft with two set screws and jam nuts. The working surface in the example shown (Fig. 442) is turned with a raised flat part or ridge fitting into a corresponding recess in the strap, which is usually cast in brass, with lugs cast on for holding the strap together, with one bolt and two nuts for each. There is likewise an oil chamber cast on the forward half of the strap, and the strap may be ribbed to give greater strength. A ⊤ piece is also cast on the forward strap for taking the end of the eccentric rod, which is secured thereto with two bolts and two nuts for each. The rod has a ⊤ piece forged on for connecting to the strap, and a double eye for taking the link, which is of the open solid kind, coupled on the centre line, this plan necessitating a greater throw for the eccentric than the travel of the valve. The radius of the link is the length from the centre of eccentric rod to the centre of the link, the open part being accurately slotted out for taking the sliding block, which is made of steel, having a hole bored in it for receiving the pin passing through the jaw of the valve rod. The link is hung from the top, with two lifting or suspending rods, one on each side, on which a part has in some cases been forged on, acting as a guide to the link, but this is not much adopted in modern practice. The guide bar on the valve rod is square, with guide blocks secured to a plate, bolted to the top of the motion bars; these guide bars are introduced to prevent any twisting strain on the valve spindle.

In the next arrangement under notice the eccentric working surface is circular, and is held in position on the axle with one set screw, having a wrought-iron nut let into the cast iron. The straps are divided at an angle to the line of the rod, with oil cup cast on the top fitted with a hinged cover. The rod is formed with a dove-tailed piece, let into the strap, and securely rivetted thereto, while the link end of the rod has a fork forged on for taking the link, fitted with a plain pin, which is held in position with a split pin bearing on a loose washer. The expansion link is of the former description, suspended from the bottom with two side rods. Instead of the valve rod being guided with a V or square piece in a line with the rod, the sliding block is fitted to a rod, oscillating on a pin close up to the gland, and suspended with the vertical oscillating links, hung from brackets attached to the body of the boiler.

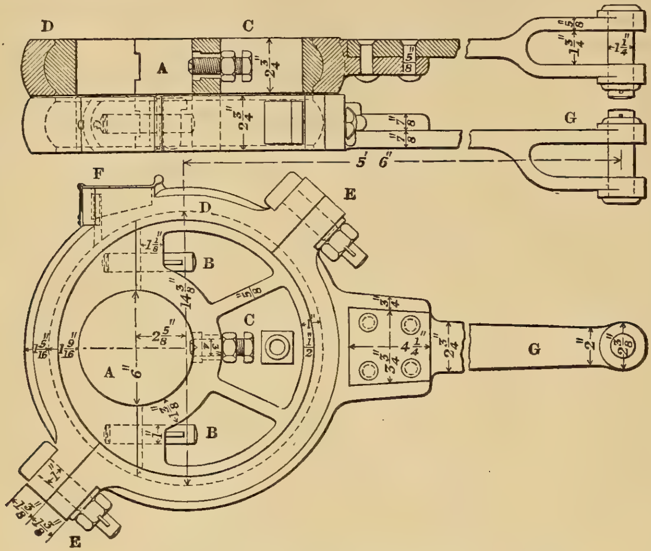
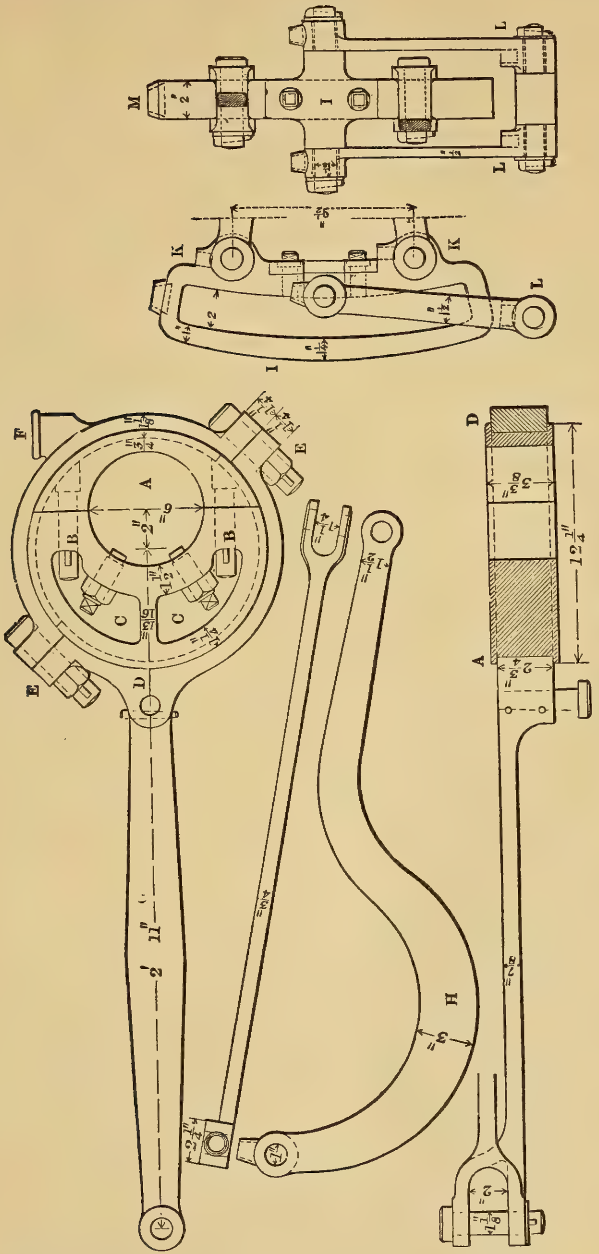


Fig. 444.—Eccentric and Rods.

A, Eccentric. B B, Pins and cotters. C, Set screw. D, Strap. E E, Snugs and bolts. F, Oil cup. G, Rod

In some arrangements (Fig. 445) the straps and rods are forged in one piece, working on cast-iron eccentrics in this example; the pump is worked from a pin on the back-going eccentric rod, having a bent rod for clearing the axle of the driving wheels, an arrangement not at all to be desired, although by this means a longer rod is obtained, which tends to lessen the thrust on the plunger gland. The link is arranged with lugs forged on for taking the eccentric rods, and the link is suspended between the two, with side links oscillating on pins forged on a piece bolted to the link. All the joints are provided with oil cups forged on as shown. The sliding block for the link is fitted as in the previous example to a rod, oscillating on a pin passing through a crosshead, fitted to the valve rod; the rod being supported by a jointed link hung from a plate bolted between the main frames.

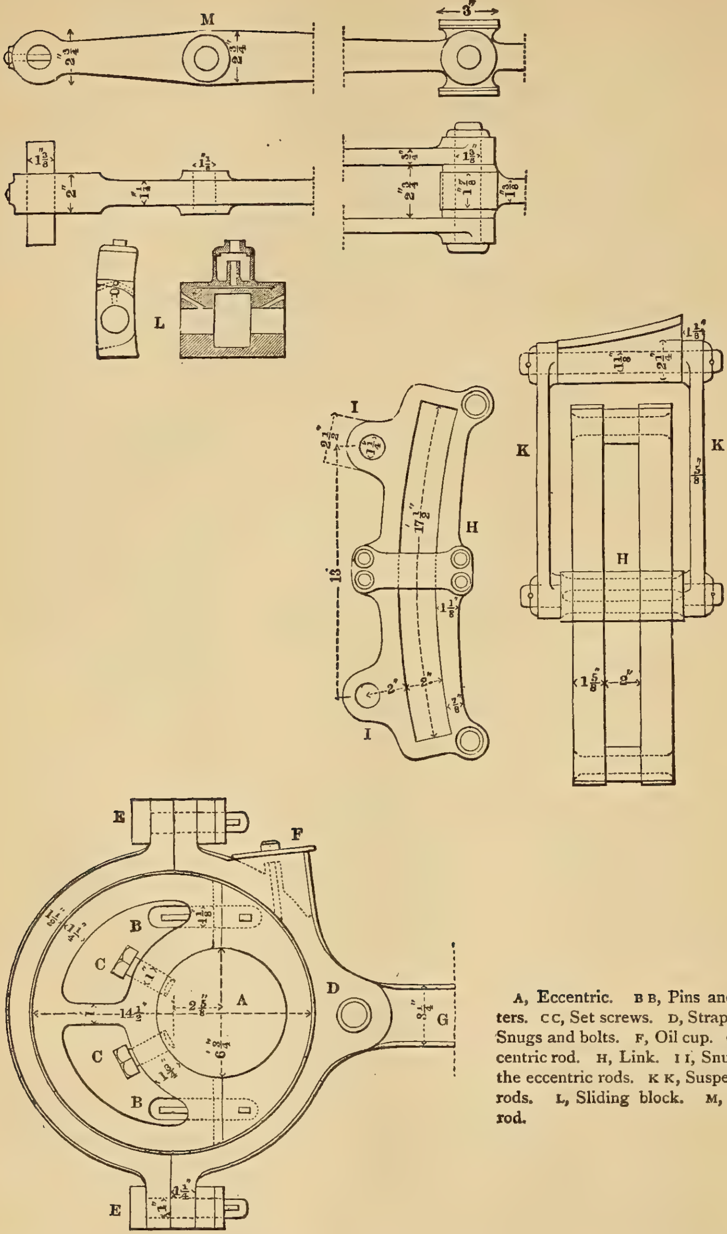
In all the preceding arrangements the links are of the lifting description; some are, however, stationary, while the connecting



Figs. 445, 446.—Back Eccentric and Rod, &c.

A, Eccentric. BB, Pins and cotters. CC, Set screws. D, Strap. E E, Snugs and bolts. F, Oil cup. G, Rod. H, Bent rod. I, Link. K K, Lugs and pins for the eccentric rods. L L, Lifting rods. M, Oil cup.

link on the valve rod moves up and down. In the example under



A, Eccentric. B B, Pins and cotters. C C, Set screws. D, Strap. E E, Snugs and bolts. F, Oil cup. G, Eccentric rod. H, Link. I I, Snugs for the eccentric rods. K K, Suspending rods. L, Sliding block. M, Valve rod.

Figs. 447, 448, 449, 450.--Eccentric and Strap, Expansive Link, Valve Rod, Link, and Sliding Block.

notice the eccentrics are of cast iron, and the strap and rod of wrought iron. The link is of the double description, rivetted together and suspended with two hanging links from a bracket secured to the boiler. The connecting link is forked at one end, taking a crosshead, which works in suitable guides. The sliding block is of course double, made in one piece, with a part cut out at the middle for the end of the connecting lever held in position with a pin passing through the block. There is a boss on the lifting link, a short distance from the end that takes the sliding block for securing the link for the up and downward motion. In some examples of valve gear it may be necessary to bend the valve rods and eccentric rods to clear the axles; this may be arranged as delineated.

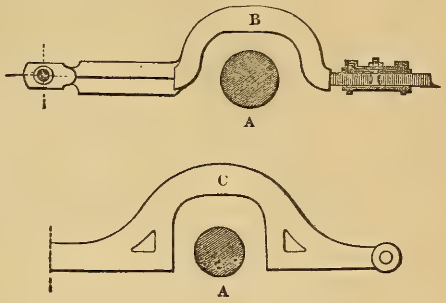


Fig. 451.—Valve Rod and Eccentric Rod.
A A, Axles. B, Valve rod. C, Eccentric rod.

A modification of the link motion more recently introduced is illustrated by Fig. 452. The expansive link is straight; the sliding block is carried on a radius link, placed between the main link and the valve rod; both are connected to a long and short lever on the weigh shaft, so arranged that the one travels up and the other down, and *vice versa*, meeting each other at half lift, the greatest vertical motion of each being only about half of that given to other link motions. Single eccentrics have been used for each valve, the reversing and expansion motion being obtained by means of spirals and wedges. Figs. 453 and 454 give a general idea of the arrangements; the angular position of the eccentrics being al-

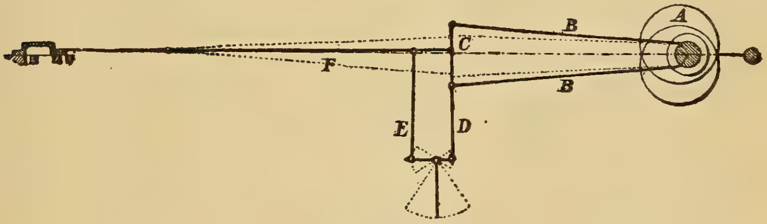


Fig. 452.—Straight Link Motion.
A, Eccentrics. B B, Eccentric rods. C, Straight link. D, Connecting link. E, Connecting link. F, Radius rod.

tered laterally with spirals on the axle, and transversely with wedges.

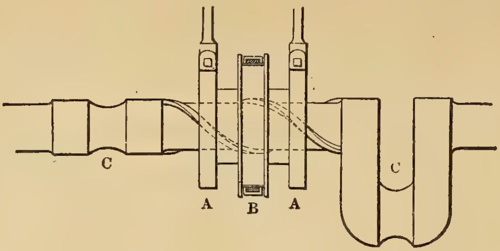


Fig. 453.—Single Eccentric with Lateral Movement.
A A, Eccentrics. B, Sheave for altering the position of the eccentrics. C C, Cranks.

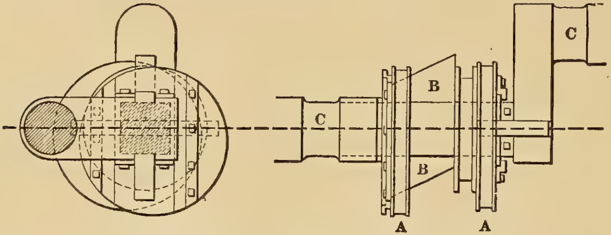


Fig. 454.—Single Eccentric with Transverse Movement.
A A, Eccentrics. B B, Wedges. C C, Cranks.

The guide bar for connecting the link motion with the valve spindle is of an elongated V section at the top and bottom; some are made of a square section, with the V at the top and bottom, which works in a guide block of brass, which is generally bolted to the back steadiment for carrying the motion bars. The guide bar has a jaw forged on at one end with a pin for taking the link and carrying the sliding block, and at the other end there is a socket for the slide-valve rod, which is secured with a cotter. The guide block is fitted with a cover,

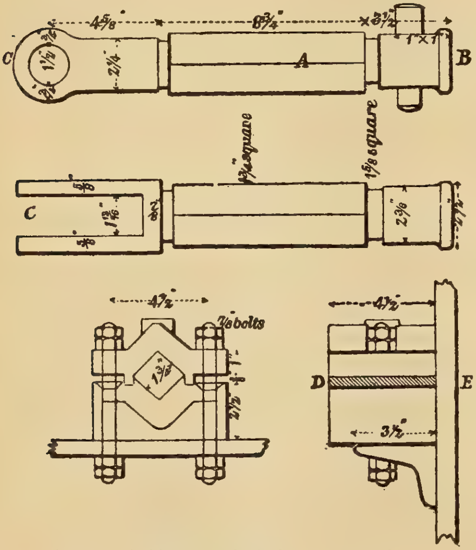


Fig. 455.—Guide Bar and Block for Valve Spindle.
A, Guide bar. B, Socket for the valve rod. C, Eye for the link.
D, Guide block. E, Motion bar steadiment.

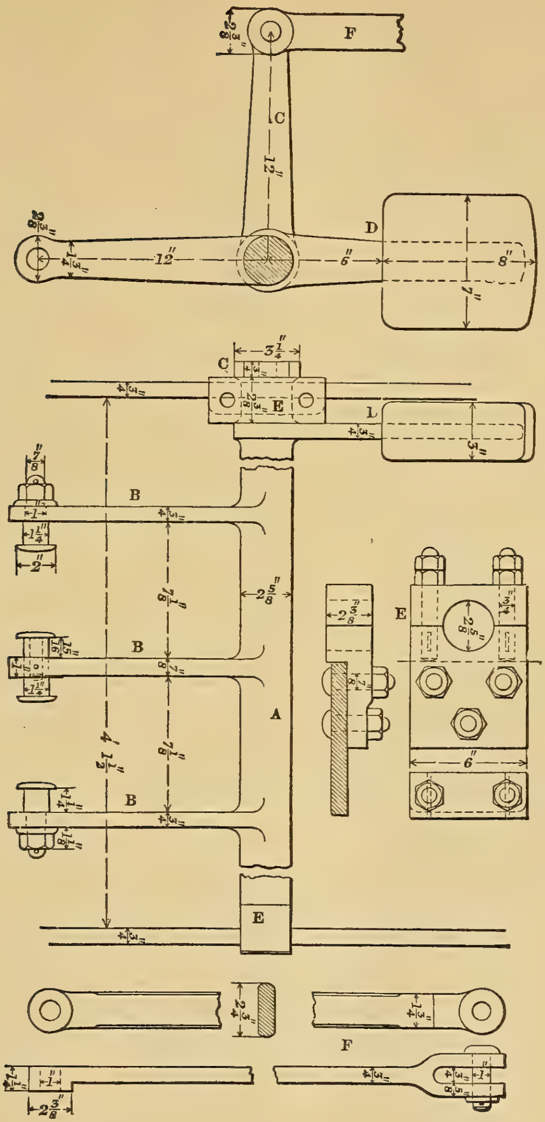


Fig. 456.—Reversing Shaft, &c.

A, Shaft. B B B, Link levers. C, Rod lever. D, Balance weight and lever. E E, Journals and bearings. F, Reversing rod.

with collar bolts for securing it to the angle iron on the steadiment, the bolts being prolonged at the top for taking the cover, and are fitted with nuts and jam nuts. In some examples with lifting links the guide bar and blocks are dispensed with, the sliding block in the link being carried by a connecting rod jointed to the valve rod; this connecting link has a jointed arm which is suspended from a pin passing through a bracket bolted to the under side of the body of the boiler, this arrangement requiring no further guide, the connections vibrating with the motion. When the link is stationary the sliding block in the link is carried up in like manner, the connecting rod for carrying the sliding block in such examples is raised and lowered with a connecting link and arm, and it is necessary to guide the valve spindle in such an arrangement, as the connecting rod lies at a considerable angle; it may be simply guided with a prolongation of the valve spindle, passing through a bracket bolted to the framing, as with outside cylinder arrangements, or any other convenient and simple guide can be used, according to the design and position of the valve gear.

The weigh bar or reversing shaft (Fig. 456) is quite parallel in some examples, and is carried up with brackets bolted to the main framing, the brackets being in the form of pillow blocks, having covers for the weigh-bar journals, while in other cases the brackets have merely solid eyes, and the weigh bar is held in position with loose collars pinned on. The lifting arms, weight arm, and reversing arm are separate forgings, which are keyed and pinned on the weigh bar. In some arrangements two lifting arms are provided, while in others there are three lifting arms, and it is now the general practice to forge them on with the weigh bar as well as the weight arm, which is weighted for balancing the motive links, &c., as likewise the reversing arm—all of which, along with the weigh bar, form one solid forging. The reversing rod has a plain flat section, and is fitted with joints at the ends for taking the reversing lever and arm of the reversing shaft.

The reversing lever is a simple lever, having the fulcrum between the end and the handle, as shown in Fig. 457, the stud for carrying it being bolted to the framing, or to the quadrant as the case may be, the lever being held in position with a loose washer and pin; it is provided with a detent which is fitted with a spring for holding it in the quadrant. The quadrant is simply two curved plates, which can

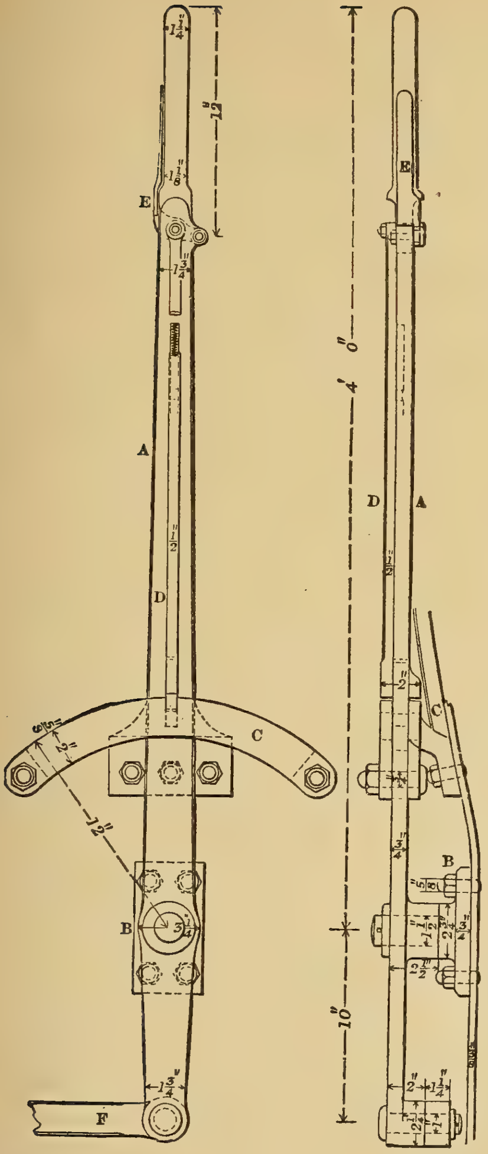


Fig. 457.—Reversing Lever and Quadrant.

A. Lever. B, Fulcrum. C, Quadrant. D, Detent rod. E, Detent lever. F, Reversing rod.

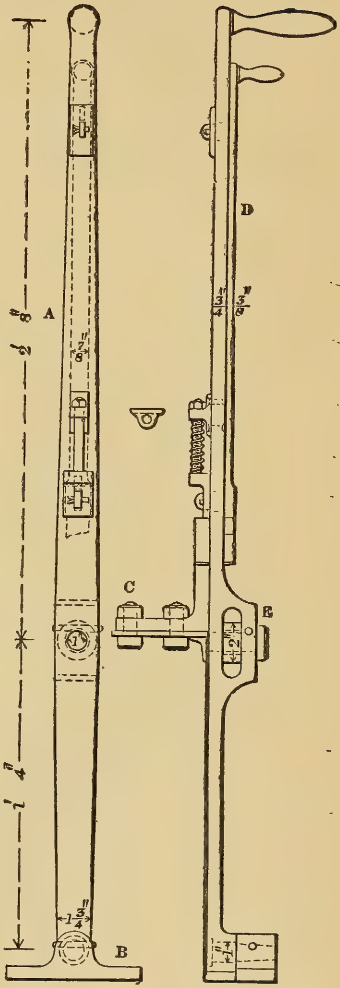
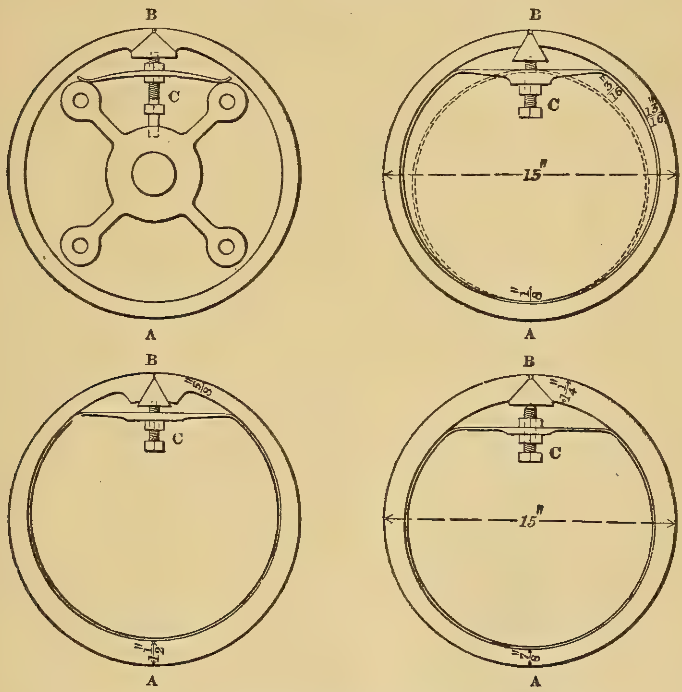


Fig. 458.—Reversing Lever and Quadrant

A, Lever. B, Bracket on the foot plate. C, Quadrant. D, Detent rod. E, Joint for reversing rod.

be variously arranged to suit the framing, or that part of the boiler, or foot plate, to which it may be bolted; the top edge has a number of slots cut in it for holding the starting lever in position when cutting off the steam at the different grades of expansion.

The *piston* consists of three important parts, namely, the body, the junk ring, and the packing ring or rubbing surface, but in some the junk ring is dispensed with. The body may be of cast iron or brass; brass is to be preferred, owing to its lightness, and not being so liable to rupture as cast iron. The junk ring is made of the same material as the body of the piston. Packing rings of cast-iron, brass, and steel rings have been used with advantage. Brass rings work smoothly, and effect but little deterioration on the surface of the cylinder, but they wear rapidly and require frequent renewal. Cast-iron rings are the most durable, and when properly fitted and well attended to when first put in, give but little trouble, working smoothly and keeping the cylinder surface in good condition,—that is to say, when the cylinder is cast in hard metal, but when the metal is soft the packing rings should be of a composition of 2½ oz. tin and ¼ oz. zinc per pound of copper: this is found to answer well, keeping the cylinder surface highly polished. The packing rings should be easy in action, as the cylinder has a tendency to wear oval, owing to the weight of the piston. Packing rings cut in four segments accommodate themselves better to the unequal wear, and cause more equal friction on the rubbing surfaces, than a ring cut at one point; as the rings, having a wedge piece and spring for pressing them up against the cylinder surface at each division, four wedges and springs will in the former case be used, whereas when the ring is cut only at one point the wedge must be pressed up with greater force, which, acting on one point, must produce unequal friction, the point where the ring is cut being that of greatest friction, while that of least friction will be directly opposite. It is customary, therefore, to make the ring thicker at the part where it is cut to allow for the wear, and gradually tapering to a less thickness directly opposite the wedging pieces. It has been found practically that the four segments equalize the pressure on the surface of the cylinder, the rubbing surfaces wearing equally; whereas when the ring is cut at one point the wear is greater at that point, while the single ring is not so durable. Single rings are sprung into the cylinder, consequently they act partly with their own elasticity; therefore, the wedge does not require to be pressed up so hard at first, until the inherent elasticity is nil, and then the wedge and spring are pressed up accordingly. The springing of the ring is effected by turning it nearly ⅛ inch larger in diameter for ordinary pistons; a part is then cut out, so that when the ring is compressed the joint is hard up, the ring fitting tightly into the cylinder: the part cut out need not exceed ⅜ inch or so. The ring when new of course acts with its own elasticity, the expansive force being more uniform throughout the ring; it is then in its best working order. As it wears the elasticity is destroyed, and the ring is expanded by the wedge and spring, which tends to throw the strain on one point, locating the wear of the surface at that part of the ring and cylinder surface. When single cut rings are adopted they should be sprung against that part of the cylinder which has the least wear. Taking the weight of the piston into consideration, least wear must take place on the top surface of the cylinder; and when two rings are



Figs. 459, 460, 461, 462.—Piston Rings, showing the Wedge Pieces and Springs.
A, Piston rings. B, Wedge pieces. C, Spring with set bolts and nuts.

used, which is generally the case, the wedging pieces should be placed on each side of the vertical centre line, thus tending to keep the cylinder truly cylindrical. The wedge should be made at an angle of 70°, thus securing free action laterally and radially. When made sharper it is more powerful in pressing out the ring, but has a tendency to gag it; while with a more obtuse angle the range is shorter, the thrust being reduced, and the radial thrust given by the spring is increased, throwing more stress on the ring and cylinder surface. The springs are in one continuous piece, or short springs are adopted for packing rings cut at one point; but when more wedging pieces are introduced, the ring being in segments, four or more springs are required, just depending on the arrangement. The set screws are generally fitted with jam nuts, the screw passing through the spring, or in some it is screwed into the spring and held in position with jam nuts. The packing rings are concentric in some cases, while in others eccentric rings are adopted, the latter being cut at the thickest or thinnest part. When cut at the thickest part, they wear better and last much longer than those cut at the thinnest part, while concentric rings seem to answer all the requirements. However, we certainly prefer, with single cast-iron rings, the wedge fitted to the thick part of the ring, as has already been described, taking into consideration the unequal wear of the cylinder surface due to the weight of the piston and adjuncts. The weight of the piston is sometimes carried up, by having a metallic piece inserted between the rings and the body of the piston, which is located at the bottom side bearing on the bottom of the cylinder; thus the body and rings are kept as nearly as practicable in their original position.

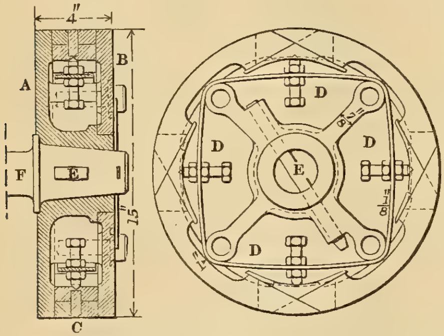


Fig. 463.—Piston with Packing Ring in Four Segments. A, Piston. B, Junk ring. C, Packing ring. D D, Springs with set screws. E, Cotter. F, Piston rod.

The various arrangements of pistons now claim our attention; the example under notice has one packing ring, cut into four segments, the ends of which are half-lapped, fitted with tongues to make them steam-tight. The wedges are cut at an angle of 122°; their radial movement being small, they never rub on the cylinder surface, and do not therefore tend to form ruts. The ring being cut in four segments, the action of the wedges is very free, superior to that of a single sharp wedge acting on a single ring cut at one part, while the wedges work more truly as the rings wear, differing less from the angles of the openings. The spring for pressing the wedges up to the packing ring is continuous, bearing on the four bosses for the bolts of the junk ring, which are formed on the body of the piston; by this means should any of the screws get an extra turn, the pressure is in a measure transmitted, and better diffused amongst the others. The body and junk ring, for securing the packing rings, are of brass, and the packing ring of cast-iron, the piston rod being secured with a plain cotter, passing through the central boss cast on the body of the piston.

Another form of piston materially differing from the foregoing, has two packing rings, with one wedge, spring, and set screw for each, the springs being continuous. The junk ring is made of extra thickness, with five holding bolts, with holes tapped into the body of the piston, which is made of cast iron. The piston rod is secured by means of collars formed on the rod, which is firmly held with the junk ring. This plan has its advantages as there are no parts to shake loose, while there is no strain on the junk-ring bolts, the steam pressure being taken on the collars—the piston too can be turned round, by simply slackening the bolts, thus altering the rubbing surface and equalizing the wear.

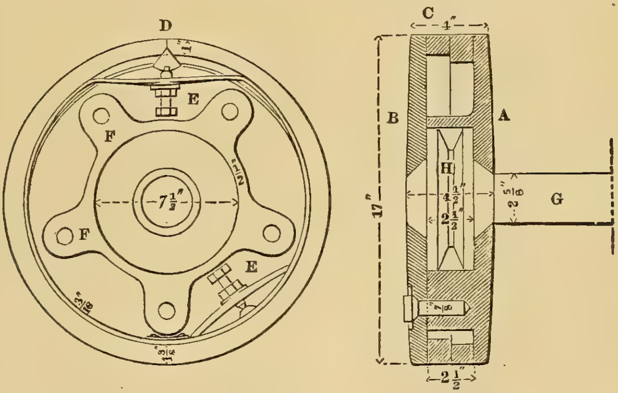


Fig. 464. Piston with two Packing Rings, with Collars formed on the Piston Rod.

A, Piston. B, Junk ring. C, Packing rings. D, Wedge piece. E E, Springs with set screws. F F, Tapped holes for bolts for junk ring. G, Piston rod. H, Collars on piston rod.

Another arrangement with two packing rings, fitted with wedges, has a short spring and set screw, the ends of the spring bearing on

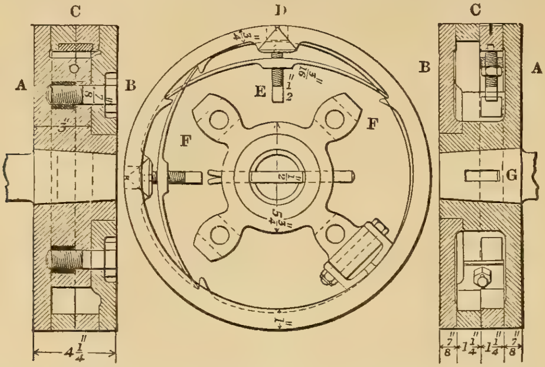
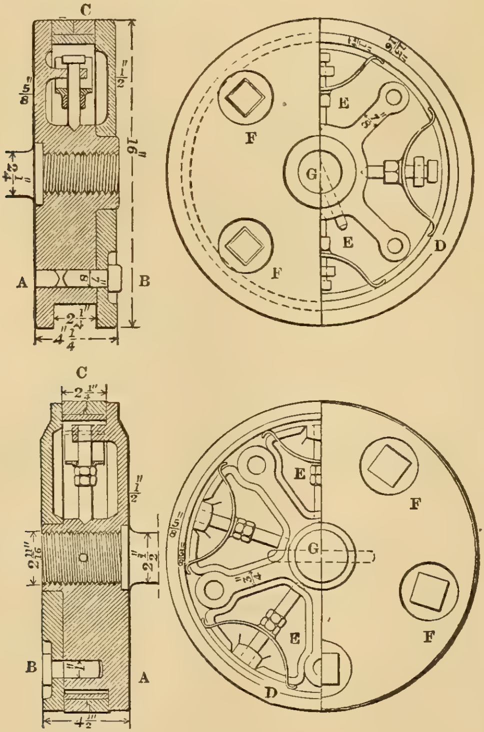


Fig. 465.—Piston with two Packing Rings, with short Springs for Wedges.

A, Piston. B, Junk ring. C, Packing rings. D, Wedge. E, Spring with set screw.
F F, Holes for bolts for junk ring. G, Cotter for piston rod.



Figs. 466, 467.—Pistons with Concentric Ring, and Concentric Spring Ring.

A, Piston. B, Junk ring. C, Packing ring. D, Concentric ring. E E, Springs with set screws.
F F, Bolts for junk ring. G, Cotter for piston rod.

projections cast along with the spring rings. The body, junk ring, and packing rings, are of cast iron; the bolts for the junk ring are screwed into brass nuts let into the body, the piston rod being firmly secured with a split cotter. There is a wrought-iron rest pinned to the body, for keeping the body and packing rings central with the cylinder.

With the view of diffusing the pressure on the packing rings, a pair of brass rings have been adopted cut at one point, inside of which is a concentric spring ring, on which springs and set screws are brought to bear, thus diffusing the pressure all round the packing rings, and as these are of brass, the friction is thus reduced. The action of the concentric spring ring, in this case, differing from the foregoing examples, is needed, inasmuch as it acts of itself as a spring keeping the two packing rings equally up to the face, which would not be the case were the small springs acting directly on the packing rings. The body and junk ring are of brass, the piston rod being fitted with a screwed end, which is screwed into the piston, and has a pin passing through the body and rod.

In one of the examples under notice the piston is parallel, while in the other one the body is deeper, thus giving a better hold for the piston rod, and it will be noticed in both arrangements that snugs are cast on the body, through which the set screws for the spring pass. We consider that these pistons are excellent examples of their class, and the packing rings when of brass, as these are, will undoubtedly wear much longer than others.

Another very good method (Fig. 468) for diffusing the pressure, as applied to single cut rings, is to have a circular steel spring, bearing uniformly on the entire circumference of the packing rings, the spring acting between the rings pressing them up to the surfaces of the piston flanges, as well as the cylinder surface, and supplying of itself the necessary range of elasticity. The rings are cut obliquely on their faces, thus preventing grooves being cut in the cylinder surface; the piston rod in this example is secured by a plain cotter. All pistons should be fitted with some means for preventing the bolts in the junk rings working backwards. A plate is shown in this example which bears on the side of the bolt heads; it is secured with two stud bolts, and two stud pins also pass through it, having a split pin bearing on the top of the plate. All the rubbing surfaces of these pistons are turned and rendered perfectly steam-tight by scraping them; formerly they were ground with emery, but the plan was bad, inasmuch as the small gritty particles became imbedded in the metal, causing great friction and deterioration of the surfaces. When all the rings are adjusted, and properly finished on their surfaces, thin slips of paper are introduced, and then the junk ring is screwed hard up; by this means the rings are held firmly in position, and then the outside circumference of the piston is finished in the turning lathe, this being required as the last operation, since in the course of fitting up the surfaces are liable to get damaged.

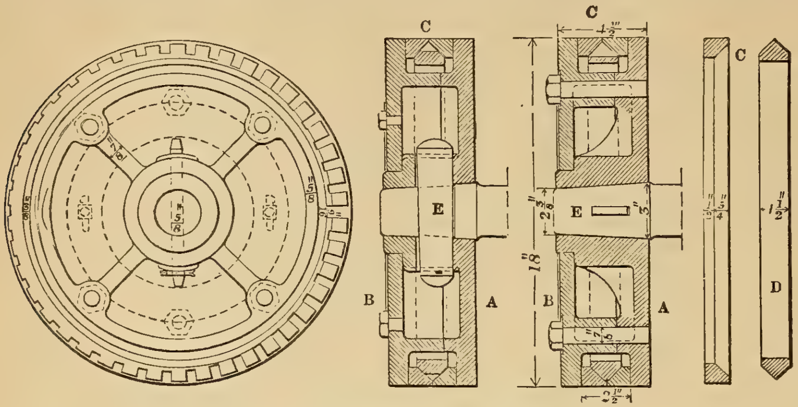


Fig. 468.—Piston with Circular Steel Spring, &c.

A, Piston. B, Junk ring. C, Packing rings. D, Circular steel spring. E, Cotter for the piston rod.

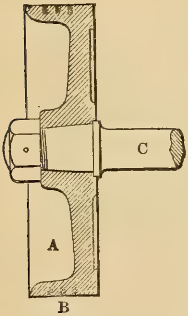


Fig. 469.—Piston with a Series of Steel Rings.

A, Piston. B, Steel springs. C, Piston rod and nut.

In order to reduce the weight of the piston, and likewise to reduce the number of parts, self-acting steel packing rings have been successfully adopted, working longer than the more complicated arrangements, giving less trouble for inspection, and requiring but little repairs. Several good examples of these steel packing rings have been in use; they are chiefly of two types, first, spring packing rings, depending on their own elasticity, and secondly, those depending on the pressure of steam admitted behind, or within the ring, to keep them up to the cylinder face. In the example under notice (Fig. 469) the piston is a solid casting, the packing rings consisting of a series of steel springs $\frac{1}{4}$ to $\frac{5}{16}$ in. square. They are made in one piece, and cut with a saw at one point, and are simply extended and sprung into grooves turned on the circumference of the piston. These plain rings work for months, and last as long as they can hold together, or until they are nearly worn through. Another form of packing ring, for solid pistons, consists of a flat cast-iron ring $1\frac{1}{2}$ inch wide and $\frac{3}{8}$ inch in thickness; the ring is made steam tight where cut with a tongue rivetted to the body of the piston, and let into slots cut in the ends of the ring, the ring being extended and sprung into the groove, turned in the piston. This piston is very light, and is well calculated to meet all the requirements.

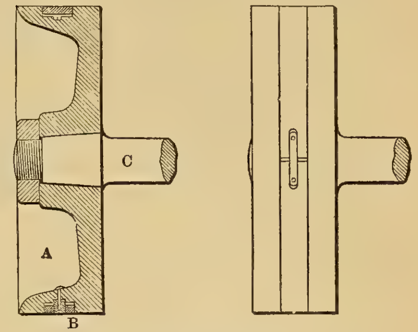


Fig. 470.—Piston with Single Cast-iron Ring.
A, Piston. B, Packing ring. C, Piston rod and nut.

Pistons depending for their efficiency on the steam being admitted behind the packing ring are constructed in a similar way; the ring, however, is made deeper, and not so broad on the rubbing surface—a small hole being bored in the body to allow the steam behind the ring. In these latter examples the piston rods are secured to the body by a nut, screwed on to a thread cut on the end of the rod.

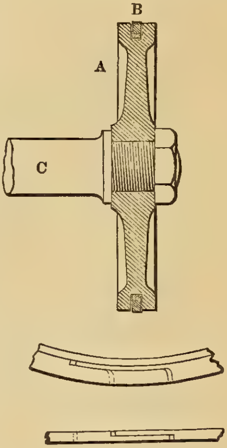
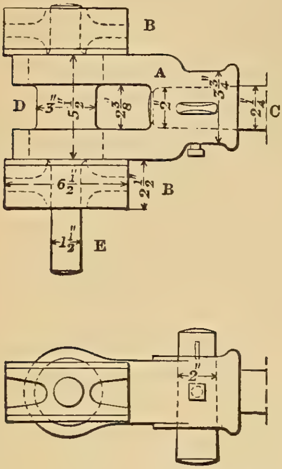
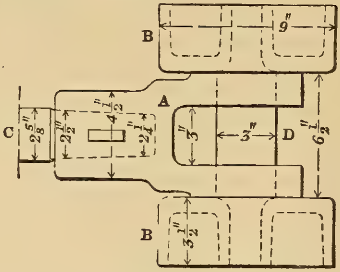


Fig. 471.—Piston with Single Ring, with Steam behind.
A, Piston. B, Packing ring. C, Piston rod and nut.

Piston rod, crosshead, and motion bars.—Piston rods are generally made of Lowmoor iron or the best scrap iron, although steel has been largely used in their construction. The part fitting into the piston has a taper of about 1 in 8 or $\frac{1}{2}$ inch for pistons 4 inches deep. They are generally secured with a split cotter passing through the boss, which is strengthened for that purpose; while in some the rod is screwed at the end, and the piston secured with a single nut, having a round split pin passing through the nut and rod, thus preventing the nut turning backwards. Sometimes the piston rod is forged along with the piston, and consequently requires neither cotters nor nut; this plan, however, has not been very generally adopted. Piston rods with flanges forged on, form a very good attachment, being very secure, having no parts to work loose, while the pressure is taken on the flanges, thus making this mode for securing the piston on the rod complete in its simplicity. The piston is held in position by the junk ring, the pressure on the back end is taken directly on the flange of the piston rod, while on the front end the strain imparted to the junk ring is simply due to the friction of the piston.





Figs. 472, 473.—Crossheads and Guide Blocks.

A, Crosshead. B B, Guide blocks. C, Piston rod and cotter. D, Gudgeon.
E, Pin for taking pump ram.

The crossheads are of wrought iron, having a part bored out for receiving the piston rod, which is secured with a nut in some cases, and a cotter in others; the taper of the rod fitting into the crosshead need not be so much as that for the piston, 1 in 20, or even 1 in 30, being sufficient. Crossheads are arranged in two ways; the best arrangement, we consider, is that in which the crosshead is adapted for single-ended connecting rods, with motion bars on each side. The crosshead is of a forked shape, with holes bored through for the reception of the gudgeon, for taking the end of the connecting rod, which is driven tightly into its place, having flat keys let into it for holding it in its position, preventing it turning round. The gudgeon is longer at one end than the other, the short end is simply for one of the sliding blocks, while

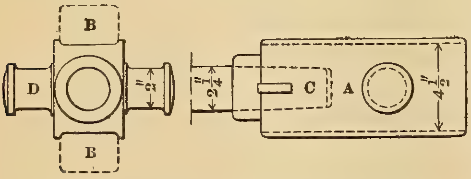


Fig. 474.—Crosshead for Single Motion Bar.

A, Crosshead. B B, Motion bars. C, Piston rod and cotter.
D, Gudgeon.

the long end likewise takes the pump ram. Crossheads for single motion bars are generally made in one piece, bored out for the reception of the piston rod, which is secured with a cotter in some, and a cotter and washer in others, the rubbing surfaces are steeled, and planed out with cross gutters, cut out for lubrication. The connecting rod is forked in mostly all examples. When the crossheads are shallow the rod requires to be forked for a considerable length, to clear the ends of the motion bars, but when made of sufficient depth it is only forked to clear the crosshead; a sufficient depth is left between the motion bars, for the connecting rod to work within them. Some of these crossheads are made to receive a single-ended connecting rod; the plan, however, is bad, as the connecting rod is shortened, the point of attachment being overhung and nearer the crank pin, while the line of action taken on the motion bars is not so perfect, and cannot act so well as when the pin for taking the connecting rod is placed central with the slides or crosshead. The crosshead in many examples is fitted with cast-iron guides, which in some are lined with white metal, but cast iron of itself works very well on iron motion bars, and is preferable to steeled guides, as the latter are uncertain, tending to cut the motion bars. These guide pieces are bored out, taking a pin at the top and bottom, which are turned on the crosshead, no other fixture than this being necessary. In the two examples we give it will be noticed that the piston rod is secured to the crosshead, with a nut in the one, and a cotter let in obliquely in

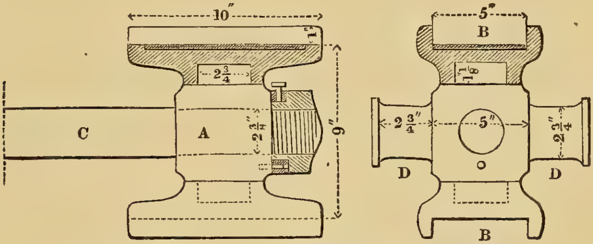


Fig. 475.—Crosshead with Cast-iron Guides lined with White Metal.
A, Crosshead. B B, Cast-iron guides. C, Piston rod and nut. D D, Gudgeon.

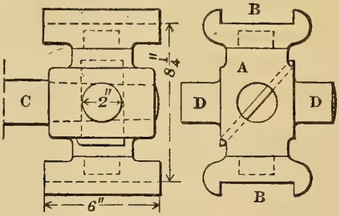


Fig. 476.—Crosshead with Cast-iron Guides.
A, Crosshead. B B, Guides. C, Piston rod and cotter. D D, Gudgeon.

the other. In some examples there is an oil-receiver formed on the brass or cast-iron guides for holding oil for the lubrication of the crosshead, while in others provision is made on the motion bars. The guide blocks have occasionally been secured to the crosshead with stud bolts, this plan being adopted when blocks have been made of extra length, and affording a secure attachment under the circumstances. In mostly all these examples the part taking the piston rod is turned, and all the other parts planed or slotted in the machine.

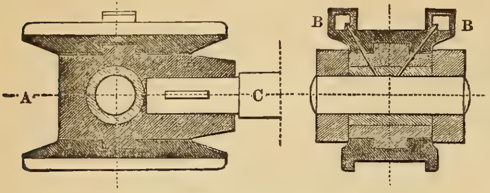


Fig. 477.—Crosshead showing Oil Receivers.

A, Crosshead. B B, Oil receivers. C, Piston rod and cotter.

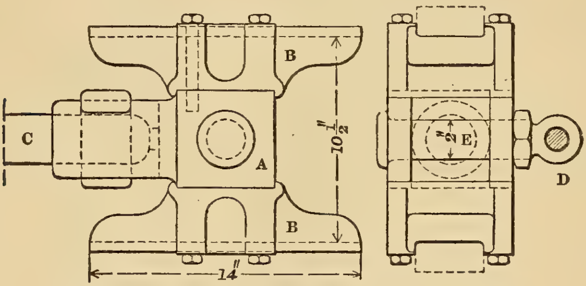


Fig. 478.—Crosshead with Guide Blocks secured with Bolts.

A, Crosshead. B B, Guide blocks. C, Piston rod and cotter. D, Eye for pump ram. E, Gudgeon.

The motion bars (Figs. 479, 480) are made of scrap iron steeled or case-hardened. Sometimes solid shear steel bars have been adopted, while cast-iron has been used with great success. The motion bars now generally adopted are of a flat section, and are secured with bolts to the back cylinder cover seats, with side joggles cast on the cover for their reception; the back end taking the blocks, which are forged along with the motion plate, or rivetted thereto, the motion plate being secured to the longitudinal frames of the engine. Sometimes the motion bars are not connected to the cylinder cover, but are secured to a front and back motion plate, which is bolted to the longitudinal framing, flanges being forged on the motion plates for that purpose. Thin strips of brass or copper are placed between the motion bars and their seatings; by this means the wear on the crosshead guides is adjusted by simply filing a little off the lining pieces. When cast-iron motion bars are adopted they are sometimes fitted with a clip at the cylinder end, with a flange cast on the back end for bolting to the motion plate, and the bar is strengthened with a vertical feather cast along with it, tapering from nothing at the end to a sufficient depth at the middle of the bar, this being required, as the cast-iron is not so well calculated for taking the strain. Attempts have been made to dispense with the crosshead and motion bars, this being effected by means of a prolongation of the piston rod, which is forged along with the crosshead and piston rod proper, the rod working in a long boss, which is secured to what would otherwise be termed the motion-bar plate. The piston rod requires to be of extra diameter for taking the strain, and a

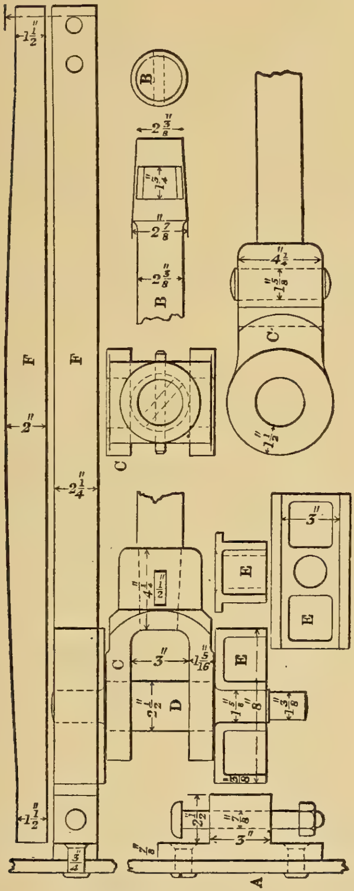


Fig. 479.—Double Motion Bars. Crosshead with Brass Guides, &c.

A, Bracket on motion plate. B, Piston rod. C, Crosshead. D, Crosshead gudgeon. E, Guide blocks. F F, Motion bar.

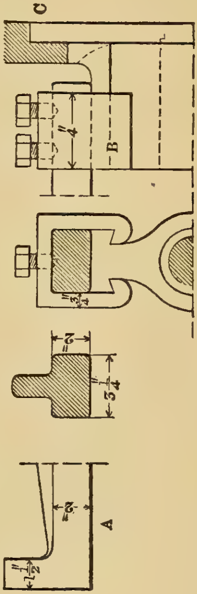


Fig. 480.—Cast-iron Motion Bars, &c.

A, Motion bar. B, Clip. C, Cylinder end.

hollow or tube section has been adopted; this plan for guiding the piston rod in a true line necessitates a long fork on the connecting rod. This peculiar arrangement, as applied to the locomotive engine by Messrs. Sharp & Stewart of Manchester, has not found much favour. It is, however, decidedly more cheaply executed than the ordinary motion bars and adjuncts, but we think it should be confined to agricultural engines, moving at a slow rate of piston.

The plate for carrying the back end of the motion bars is forged in some instances, with provision for carrying the end of the pump; and has flanges at the end fitting against the longitudinal frames, to which it is securely bolted. In other arrangements the motion plate is formed of plate iron, with angle-iron flanges for securing it to the main framing. It is generally made of considerable depth, with holes cut out for the connecting rods and eccentric motion rods, and sometimes the plate is carried up and securely rivetted to the boiler, in fact, forming the support for the boiler; this is to be preferred to the old method, having the boiler brackets bolted thereto, and likewise to the rigid framing, as the plate is not so rigid, yielding to the expansion and contraction of the boiler. The motion plate for outside-cylinder arrangements is carried beyond the framing, extending the whole width across the framing, with a long hole cut out for the wheel coupling rods, working through the plate extending from nearly the centre of the boiler to within a few inches of the rails.

Connecting rods.—Much attention has been paid to the construction of the connecting and the coupling rods. The body and the straps are of scrap iron, with brass bushes and steel cotters. The length of the connecting rod from centre to centre should be six times the length of the crank, and even longer when convenient, shorter connecting rods throwing an undue strain on the motion bars, causing much friction. In former examples the body of the connecting rod was turned, but this plan, although cheaper, was objectionable. Flat sections are now universally adopted, as that form gives rods much stiffer, and better calculated to take the severe strains they are subjected to. Long forked connecting rods should, as far as practicable, be discontinued, as forked ends are not nearly so strong as plain ends; short forks, however, are extensively adopted, and are not so objectionable, although we decidedly prefer single ends.

For inside-cylinder arrangements each end has a butt forged on the body, which is planed for the reception of the strap, the bushes being placed between the butts and the loop ends of the straps. The latter are tightened up with jibs and cotter, by this means adjusting the wear on the bushes. The cotter is held with two side screws for the large end and a single set screw for the small end, and for further security split pins are inserted in holes on the bottom end bored at a short distance from each other. In other examples the cotter is prolonged and cut with a screwed part which passes through a hole in a prolongation of the jib; by this means the cotter is held in position with jam nuts. The bush and strap at

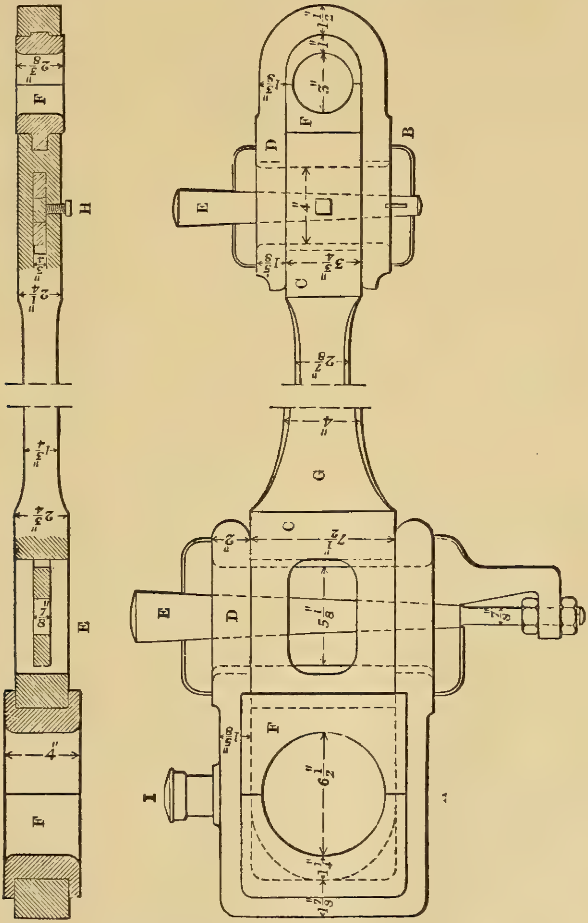


Fig. 481.—Connecting Rod with Single Ends.

A, Crank end. B, Crosshead end. C C, Butts. D D, Straps. E E, Jibs and cotters. F F, Brasses. G, Body. H, Set screw. I, Oil cup.

the large end are square, surface thereby being gained for taking the thrust. The butt has a large hole cut out, for lightening it, tending to reduce the balance weights placed on and between the spokes of the driving wheels. The bush for the small end of the rod is tightened up with a single key and jibs, with side nut for holding the key in position, as likewise a split pin on the under side. In another example (Fig. 482) the small end is forked; the bushes at both ends are lined with white metal; the ends of the bushes are not square, but

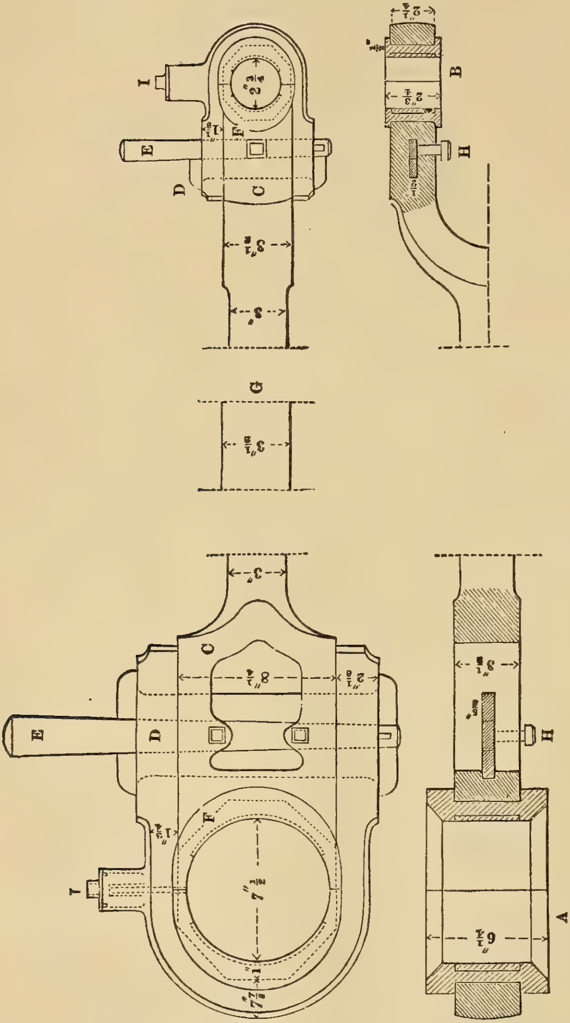


Fig. 482.—Connecting Rod with Forked End.

A, Crank end. B, Crosshead end. C C, Butts. D D, Straps. E E, Jibs and cotters. F F, Brasses. G, Body of piston. H H, Set screws. I I, Oil cups.

are fitted into parts cut out in the connecting rod and straps, like an ordinary pillow block for land engines. The strap on the large end is tightened up with jibs and a single cotter, and at the forked ends with a single jib and cotter, having set screws and split pins as before. The cups for lubricating the crank pin and gudgeon for the crosshead are forged on, and fitted with a siphon pipe and cover to prevent the oil being thrown out with the rapid revolving and reciprocating motion the connecting rod is subjected to.

Owing to this rapid motion it is found advisable to secure the strap at the crank end with two bolts and two nuts to each bolt, thus binding the strap and butt firmly together; there is a single cotter bearing on the bush for adjusting the wear, the set screws for holding the cotter in position being screwed into the strap, the small end in this example having a cotter and two jibs for the bush. The siphon cups are forged on the straps, and the cover is fitted with an internal plug bearing on it, and which is held up with a light spiral spring. In another plan for holding the strap in a fixed position two sets of jibs and keys are adopted, with joggles formed on the large butt (Fig. 484). One set draws the strap into the joggle, where it is firmly held, the cotter being secured with set screws and split pin, while the other set bears directly on the bush, and are only used for adjusting the wear. The siphon cup is forged on the large strap, and the small end is provided with a brass

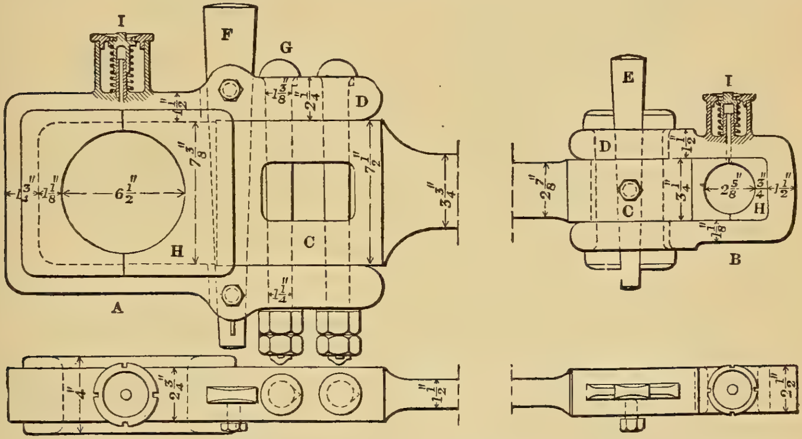


Fig. 483.—Connecting Rod with Fixed Strap, having Bolts passing through the Strap and Butt.

A, Crank end. B, Crosshead end. C C, Butts. D D, Straps. E, Jib and cotter. F, Cotter G, Bolts and nuts. H H, Brasses. I I, Oil cups.

cup screwed in the strap, which is an advantage when the cup requires cleaning; but it is preferable to forge them on the large ends, owing to the violent motion, which is liable to shake brass cups loose. The slightest derangement in this important part will with an attentive driver cause a stoppage, perfect lubrication of the crank pin being necessary; and indeed all the moving parts of a locomotive must be plentifully supplied with oil or other lubricant.

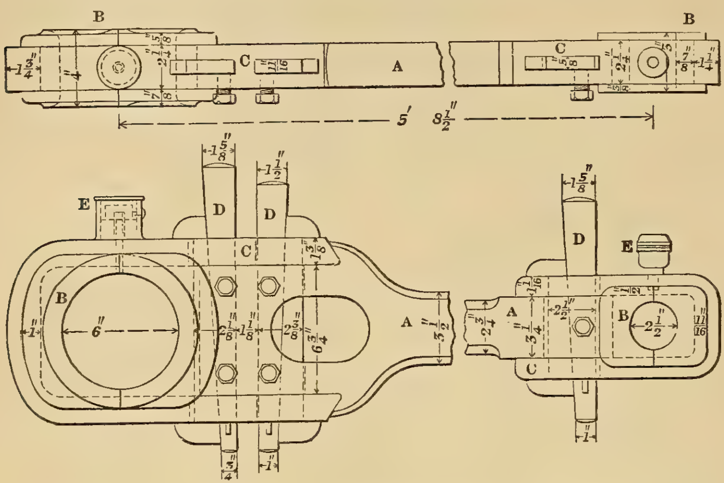
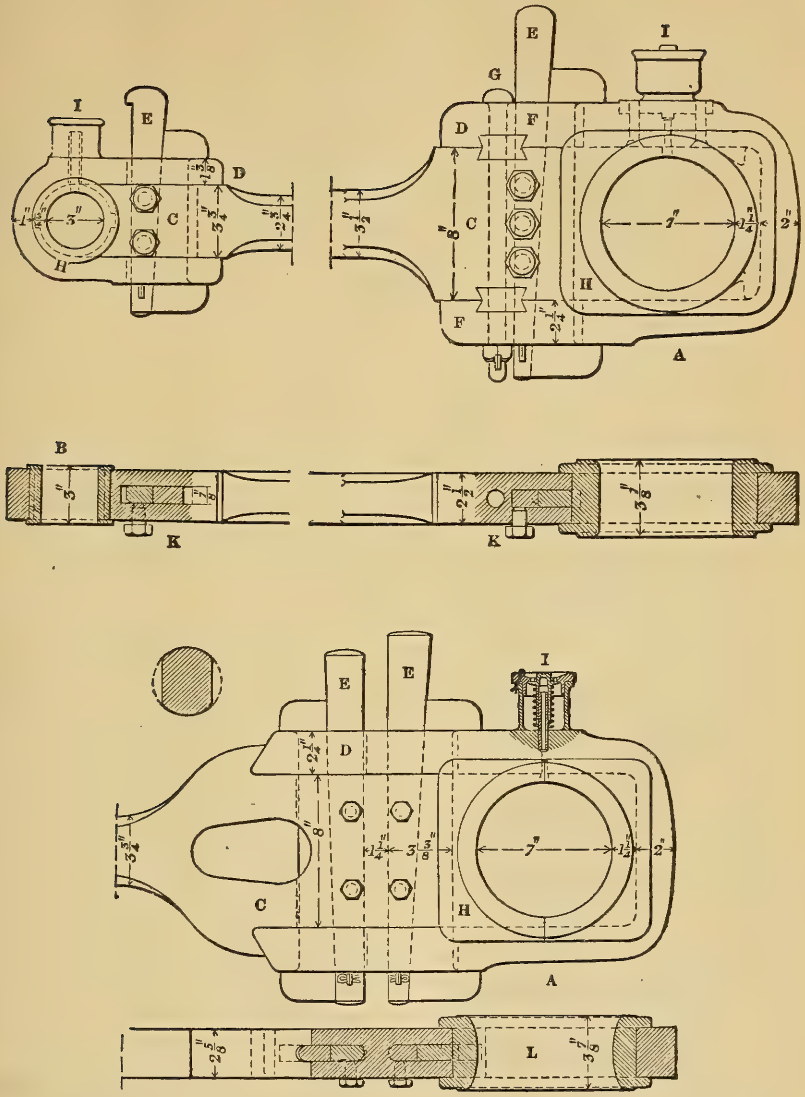


Fig. 484.—Connecting Rod with Fixed Strap secured with Jib and Cotter.

A, Body of connecting rod. B B, Brasses. C C, Straps. D, Jibs and cotters. E E, Oil cups.

In some examples (as Fig. 485), not at all to be commended, dovetailed pieces are let into the strap and butt, with a single bolt for securing them, passing through and through. It is evident that the dovetail weakens the strap, and when the strap becomes loose it is sure to fracture at the weakest part; we therefore consider that the joggles formed on the butt are to be preferred. Some of the crank-pin bearings are rounded with the bush bored out to suit, while all the bearings should be well rounded at the corners, thereby materially strengthening the shaft. Various other forms of connecting rod ends have been applied in practice; amongst these we note an example entirely doing away with the straps (Fig. 487). The large end is cut out embracing three sides of the bush, which is held in position with a plate on the underside, and bolts passing through the butt, the bush being adjusted with a single cotter. The small end of the connecting rod is forked, and is fitted with a long bush, with jib and cotter for adjusting the bush. In other examples for small ends the wear of



Figs. 485, 486.—Connecting Rods with Dovetailed Piece let into the Strap, and Rounded Bearing for the Crank Pin.

A, Crank end. B, Crosshead end. C C, Butts. D D, Straps. E E, Jibs and cotters. F F, Dovetailed pieces. G, Bolt. H H, Brasses. I I, Oil cups. K K, Set screws. L, Rounded bearing.

the bush is adjusted with a wedge with screwed point and nut, the end being solid and cut out for the reception of the bush (Fig. 488).

In order to reduce the clearance between the cotters and the body of the boiler for inside-cylinder arrangements various forms of connecting-rod ends have been adopted; in some the bush has been adjusted with bolts and nuts, taking a cap bearing on the bush, a T form of connecting-rod end being adopted with the distance piece between the cap and end cast along with the bush (Fig. 489); these connections have not been much used in the locomotive, although they have been largely adopted in marine practice.

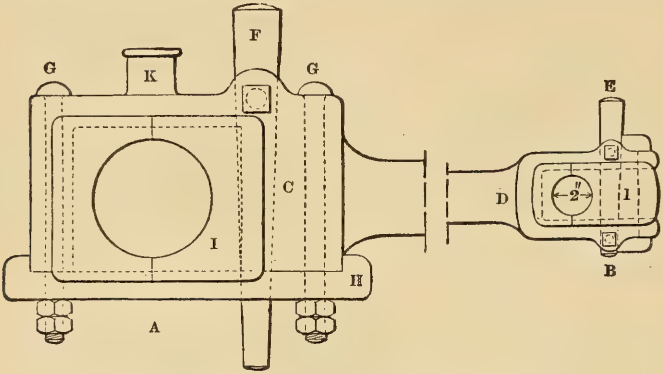


Fig. 487.—Connecting Rod with Solid End and Plate.

A, Crank end. B, Crosshead end. C, Butt. D, Forked end. E, Jib and cotter. F, Cotter. G G, Bolts and nuts. H, Plate. I I, Brasses. K, Oil cup.

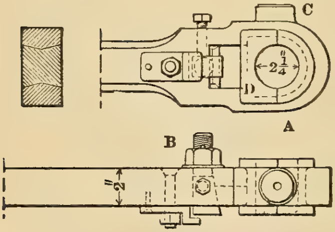


Fig. 488.—Connecting-rod End with Wedge Adjustment.

A, Solid end. B, Wedge. C, Oil cup. D, Brasses.

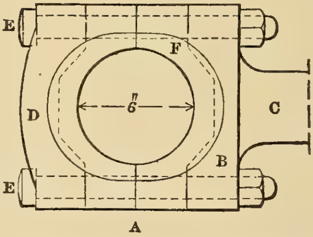


Fig. 489.—Connecting-rod End fitted with Cap and Bolts.

A, Crank end. B, T piece. C, Body. D, Cap. E E, Bolts and nuts. F, Brasses.

Connecting rods for outside-cylinder arrangements materially differ from those for inside arrangements with cranked shafts, the end taking the crank pin being much reduced; it is generally forged solid and cut out for the reception of the bush, which is adjusted with a single key, the end for the crosshead being fitted with strap, jibs, and cotter as for inside-cylinder arrangements.

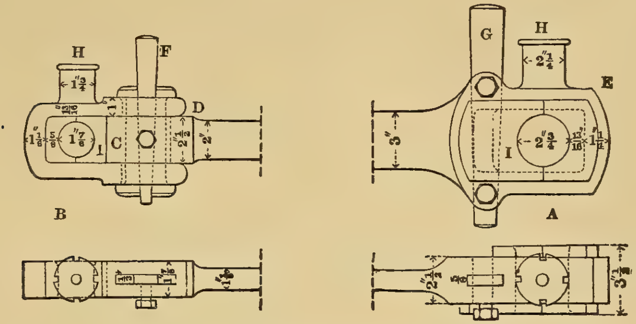


Fig. 490.—Connecting Rods for Outside Cylinders.

A, Crank end. B, Crosshead end. C, Butt. D, Strap. E, Solid end. F, Jib and cotter. G, Cotter and set screws. H H, Oil cups. I I, Brasses.

The crosshead end in some being single, while others are made with a short fork for taking the crosshead, all the cups for the lubrication

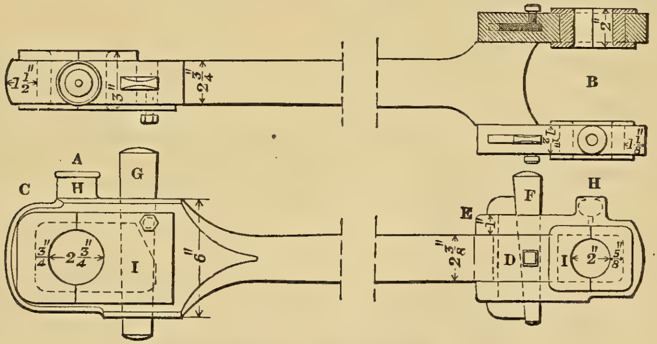


Fig. 491.—Connecting Rods for Outside Cylinders.

A, Crank end. B, Crosshead end. C, Solid end. D, Butt. E, Strap. F, Jib and cotter. G, Cotter. H H, Oil cups. I I, Brasses.

of the crank pin and crosshead gudgeon are generally forged on along with the butt and strap. In some examples straps are likewise used for the crank end, and in some forked ends have been successfully adopted (Fig. 492), the bush being adjusted with a jib and cotter; it is evident this form of connection is not so safe as the solid ends or those fitted with straps; it will be observed that the jaws of the fork are kept from springing with a tie piece, taking the two set screws for the cotter.

The rods for coupling the wheels should have the ends forged in one piece; they are generally fitted with parallel brasses, having an elongated flange on the same side as the cotter, which is adopted for adjusting the wear, the cotters being placed each on the same side of the crank pins as the other; this is required to preserve the true distance from centre to centre. The cotter is held in position by two set bolts screwed into snugs formed on the butts, and by a split pin at the under side of the cotter. Sometimes a metallic piece is inserted between the bush and the cotter for taking the strain. The lubricating cups are of brass, or forged on and bored out, and fitted with siphon pipe having a cotton wick, by which means a constant supply of oil is kept up, the lubricant falling on the pin drop by drop. Without this appliance oil poured into the cup would run to waste, and the pins would soon become serrated; in fact, the simple application of cotton-wick siphons to the various oil cups distributed over the locomotive engine tends in a great measure to its success.

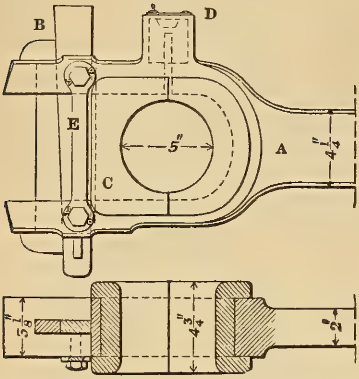


Fig. 492.—Connecting Rod for Outside Cylinder with Forked End.

A, Forked end. B, Jib and cotter. C, Brasses. D, Oil cup. E, Tie piece.

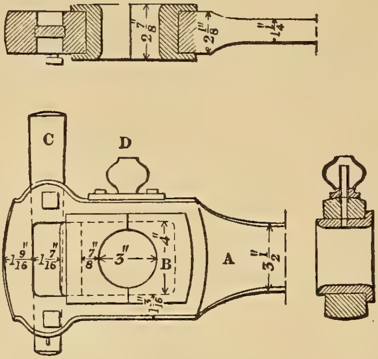


Fig. 493.—Coupling-rod End.

A, Solid end. B, Brasses. C, Cotter and set screws. D, Oil cup.

When the leading and trailing wheels are coupled to the driving wheels, a joint with a pin is introduced; in some cases it is placed between the driving and trailing wheels, while in others it is placed between the driving and leading wheels. This joint is located close up to the bushes, and is introduced to prevent the rod becoming bent by the irregular vertical motion and vibration of the framing and wheels, owing to irregularities in the permanent way.

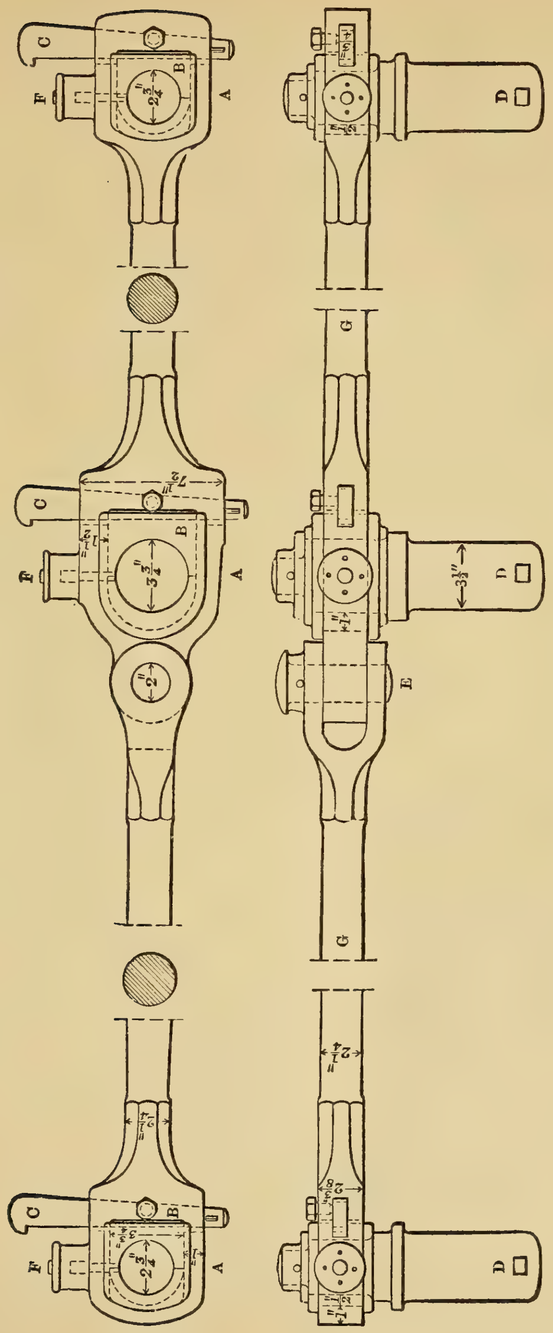


Fig. 494.—Coupling Rods and Outside Crank Pins.

A A, Solid ends. B B, Brasses. C C, Cotters and set screws. D D, Crank pins. E, Joint and pin. F F, Oil cups. G G, Bodies of rods.

The pins for taking the rods are either fitted into holes bored out in a solid part formed along with the spokes of the wheel, or separate cranks are adopted. In some examples the ends of the coupling rods are quite round, a simple eye being forged on the rod, which is bored out for the reception of a thick round bush, which is held in position with a washer and nut, the end of the crank pin being screwed. In mostly all examples the body of the rod is of a flat section, while in others it is turned, and in some the top and bottom are turned and the sides flattened.

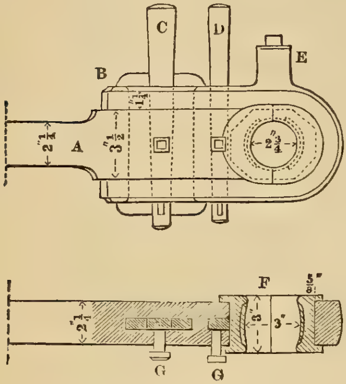


Fig. 495.—Coupling-rod End.

A, Butt. B, Strap. C, Jib and cotter. D, Cotter. E, Oil cup. F, Brasses. G G, Set screws.

Coupling rods have been fitted with straps, with two jibs and cotter for holding the strap rigid, and a single cotter for adjusting the wear of the bush, which in many instances is bored out to fit a spherical-shaped pin. We certainly prefer the ends of the coupling rods forged in one piece, and such ends are universally adopted; they are better calculated to meet the violent motion these rods are subjected to. All the parts should be as rigid as practicable, with no part liable to shake loose.

Cranked axle.—When the cranked axle is arranged with a main outside bearing it must have a narrow bearing placed close up to the cranks, as when the main bearing is outside of the wheels it is imperative that the cranked axle should be supported close up to the

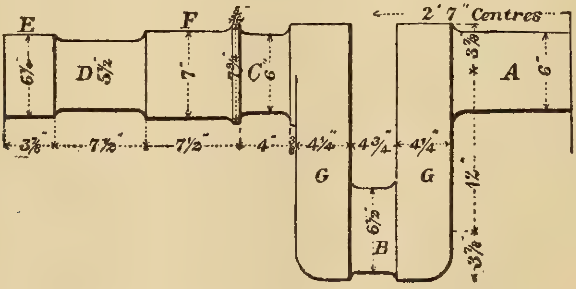


Fig. 496.—Cranked Axle.

A, Main body of axle. B, Crank pin. C, Inside journal. D, Outside journal. E, Part for outside cranks. F, Part for wheel. G G, Crank.

cranks; but in many examples of inside-cylinder engines the axles have no outside bearings, but simply a broad bearing with the side of the brasses rubbing quite close against the flat sides of the crank. This plan has been very generally adopted both for broad and narrow gauge engines; it is certainly much simpler than the cranked axle having outside bearings on the main framing and likewise narrow bearings fitted to the horn plates; moreover the breadth over all is greatly reduced, the outside coupling rods being placed quite close up to the wheels. In manufacturing cranked axles a long slab is hammered up, and then swaged down in the middle and at the ends; the throws are then worked into shape, and the axle is then twisted at the central part, until the throws are at right angles with each other—the grain of the iron running across the throws; by this method they are not so liable to split through. Some cranked axles are bent with the aid of hydraulic machinery, a long bar being heated and put into the machine; the throws are formed with a die and mould, the die being pressed up by water power: these axles give great satisfaction. When the axles are delivered at the factory the throws are generally solid with the ordinary method of construction; they are then slotted out, and the axle is then turned in a lathe. All the corners of the bearings should be well rounded, as the axle is greatly strengthened thereby. In some the crank pin is turned of the same diameter throughout with bold curves at the corners, while in others the pin curves from the middle to the sides of the crank; by this means greater strength is obtained over those that are finished parallel. The ends of the crank throws are rounded at the outside corners, thereby reducing the weight, while others are left quite square, the extra weight being balanced on the wheels. In some examples a wrought-iron strap has been shrunk on each crank, with the view of binding the fibre of the iron better together; this we consider may be to a certain extent advisable, although it adds more weight, which must be properly balanced; on the other hand, when due attention is paid to the selection of the scrap iron, with good workmanship, and with the improvements

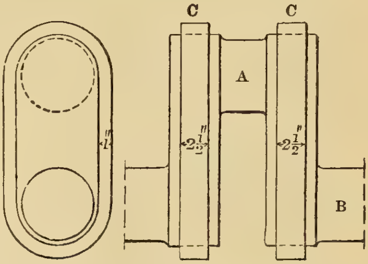


Fig. 497.—Straps on Inside Cranks. A, Crank pin. B, Axle. C C, Straps.

in manufacture, we consider these straps not at all necessary, and they are but little used in modern practice. With plain driving axles used for outside-cylinder arrangements the bearings are placed inside of the wheels in a similar manner as for cranked axles, having no outside bearings, while the crank pin is rivetted into a hole bored out in a boss forged along with the wheels. When the wheels are coupled together the crank pin has two bearings, one for the coupling rods placed close up to the wheel, while that for the main connecting rod is placed outside of it considerably overhung, throwing a severe strain on the part, which, fitting into the wheel, is made conical and rivetted at the end into a countersink, thus making it very secure. The bearing for the coupling rod on the crank pin is made larger than what is actually required for the other wheels, simply to strengthen the pin for taking the strain imparted from the steam piston and connections. The connecting rod in many cases is held on with a collar forged along with the pin, while others have a nut and washer, and some a plain washer with a pin passing through it. There is likewise a collar turned on the pin between the two connecting rods, when so fitted, for keeping the brasses separate, as they would soon tear were they in juxtaposition.

Plain axles consist of four parts, namely, the body or middle, the parts for taking the wheels, the journals, and the parts for the outside cranks. To combine lightness with strength, the axle should taper from the middle to the raised parts for taking the wheels, which should be of increased diameter to obtain a large bearing surface for the eyes of the wheels; in the inside there should be a shoulder for the nave of the wheel abutting against. When fitted with outside bearings, the journals are reduced in size, while the parts for taking the outside cranks are of greater diameter than the journals. When the axle has only inside bearings all the parts are generally of the same diameter, excepting the collars for the wheels and journals. It is preferable, however, to make the part for taking

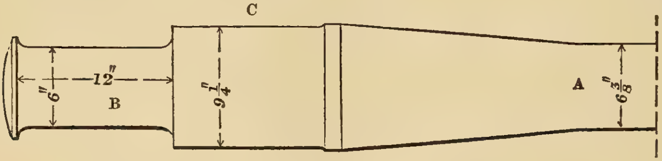


Fig. 498.—Carrying Axle.

A, Body. B, Journal. C, Part for wheel.

the eye of the wheels of increased diameter to secure a larger surface, the boss of the wheel in such cases rubbing closely against the brasses in the axle boxes, while with collars the nave of the wheel is kept the breadth of the collar apart. All the journals should be finished with a tool in the lathe, leaving well-turned curves at the corners. The old method of using emery to get a smooth surface has for long been discarded, as particles of the emery got imbedded in the iron, and soon played sad havoc when the engine was started. When the wheels are coupled the journals should be nearly of the same diameters, but this depends on the weight as adjusted with the springs.

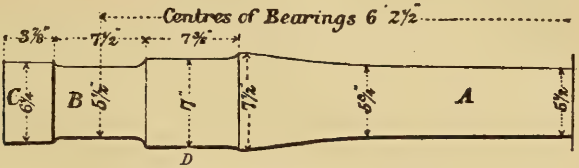


Fig. 499.—Leading and Trailing Axle.

A, Body of axle. B, Journal. C, Part for outside crank. D, Part for wheel.

Axles are generally made of scrap iron drawn out at two heats. When new iron is used it is taken from the puddling furnace, put through a squeezer, then piled, heated, and rolled twice, and finally heated, and swaged into shape. There is considerable difference of opinion as regards the manufacture of axles from scrap iron, on the one hand, and new iron on the other hand; scrap iron must necessarily vary very much; the pile may be composed of a variety of qualities of iron, such as old and new, hot short and cold short, burned and raw; and in the process of heating, one part may be burning while others are welding; thus it is difficult to pick out scrap iron that combines all the necessary qualities so essential in manufacturing a sound axle. The scrap iron generally adopted in railway workshops is old tyres taken from the carriage wheels, and this may be considered the best description that can be used for such forgings. With ordinary scrap iron the pile requires to be well drawn down in order to secure a uniform grain, as parts of the pile may be drawn out while other parts may be upset. All iron is subject to be either more or less burned or worked at too low a heat; that, combined with bad workmanship, renders it difficult to say whether new or scrap iron axles are to be preferred; we are inclined to consider, however, that axles made from new iron of good quality, and with first-class workmanship, are preferable to those made from ordinary scrap iron of doubtful quality.

Wheels consist of four parts, namely, the nave, the spokes, the inside tyre or ring, and the outside tyre. They are manufactured in a variety of ways; some have wrought-iron rings and plain spokes, with nave forged on, and some cast-iron naves, with spokes varying in section: the latter method, however, has now become obsolete. In modern practice the nave, spokes, and ring are built up, and forged in one mass. The spokes are forged with wedge pieces to form the nave, and T-shaped pieces for the inner tyre or ring; the ends of the T pieces are bevelled; thus when the spokes are put together a series of wedge spaces are left to be welded up. After the spokes are forged they are taken to the grinder to be ground quite smooth, a revolving-stone being used for that purpose. The spokes are then put together, and are held in position with a strap and screw; the nave is then placed on the fire and brought to a welding heat; at the same time a thick washer is brought to a welding heat in a fire adjacent, two smiths being required, one for attending to the nave and the other to the washer.

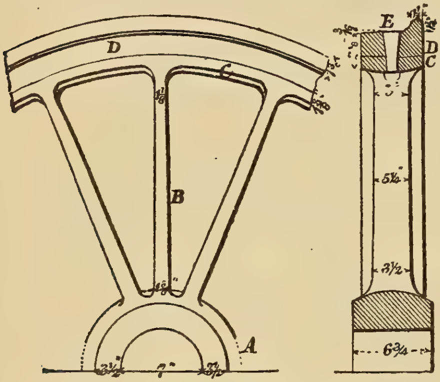


Fig. 500.—Wrought-iron Wheel.—A, Nave. B, Arm. C, Inside tyre. D, Outside tyre. E, Rivet.

The smith attending to the nave, when it is brought to a proper heat, gives the screw on the strap an extra turn, thereby forcing the series of wedge pieces more closely together. When both are ready the nave is put on an anvil, and the washer is placed on it, and a few strokes of a suitable steam hammer unite the mass; thus one side is partly finished, a washer being required for each side, the other is in like manner welded on; the nave is then dressed off with hand labour. After the nave is completed the strap is removed and a straight bar attached, with means of turning the mass over, so that the wedge space in the ring or tyre can be filled up and welded bit by bit. The spoke wheel is then taken and placed in the turning lathe, and the ring turned with a plain surface, at the same time the eye is bored out.

The outside tyres of iron or steel are generally ordered from the rolling mills in hoops entire, which are turned out with a plain surface in the factory. Both spoke-wheel and tyre are then taken back to the wheel shop, which should be adjacent to the turning department, the smith then heats the outer tyre in a furnace for that purpose, the spoke wheel being placed in a circular trough. The tyre, after being brought to a proper heat, is taken out of the furnace and placed over the ring on the spoke wheel; the outer tyre having expanded with being heated, is easily placed over the ring, and water being let into the trough, it contracts on the ring and firmly embraces it as it were in one mass. The wheel may then be fitted to the axles, which have generally the key ways cut in each. The keys are of steel, and are fitted accurately into the key beds, and are then driven in with a sledge hammer. The wheels and axle may then be taken to the turning shop and put in the lathe, the centres on the axle being left on for that purpose; thus the trods of the wheels are turned all over and finished off quite truly with the journals, as the same centres for turning the journals are used for turning the outer circumference of the wheels.

Six-wheeled engines have generally flanges on all the tyres, for preventing the engine leaving the rails; but when more wheels are adopted, with the driving wheels placed in a central position, it is better to have the tyres for the driving wheels without flanges, so that the engine can turn round sharp curves easily. A few tap bolts are fitted to holes tapped through the inner tyre, and partly tapped in the outer tyre; some are fitted with nuts which are screwed hard up, and the point of the bolt rivetted over, while the bolt is put in hot, and the point rivetted over.

Wrought-iron wheels for outside-cylinder engines have the bosses forged along with the arms for taking the crank pin; weights for balancing the crank throws, connecting rods, &c., are fitted to the wheels inside of the inner tyre or ring, having side plates for keeping them in position, which are held together with bolts rivetted over. In some the balancing power has been put into the inner tyre, this being forged of greater thickness at one part for that purpose.

Wheels of small diameter are sometimes made of cast iron, and are suitable for waggons, &c. The usual practice is to cast the nave, arms, and ring together, and fit the outside tyre of iron or steel in the usual manner. The arms are made of a strong sectional area, as likewise the ring; a T form of arm was formerly adopted, but in modern practice solid arms are the rule, though some are made hollow in the casting as well as the naves. Much attention has been paid to wheel castings in order to prevent them cracking from the unequal expansion of the cast iron. A wheel properly proportioned in all its parts will give way if one part is cooled sooner than another part; for instance, the ring being thinner than the boss, contracts rapidly, the great body of metal in the nave being still in a fluid state, which in cooling tears away from the rim; it was therefore found necessary to divide the nave, and afterwards fill up the spaces with iron plates, two wrought-iron hoops being shrunk on the nave, one on each side, similar to the fly wheel of a land engine. Cast-iron locomotive wheels are now annealed in a kiln for that purpose. A deep pit made of brickwork is heated red-hot, and while

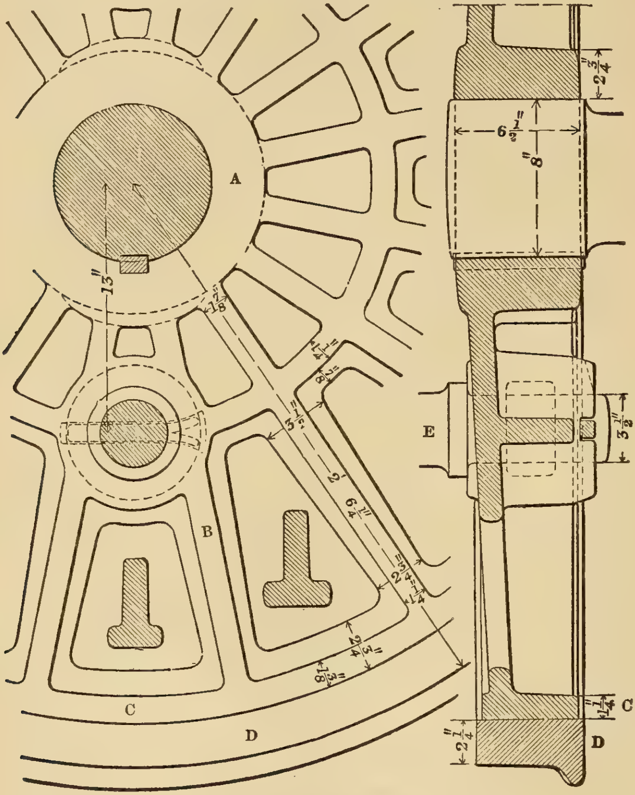


Fig. 501.—Cast-iron Wheel.

A, Nave. B, Arm. C, Inside tyre. D, Outside tyre. E, Crank pin and boss.

the wheel is red-hot it is taken from the mould and placed in the kiln, which is then covered to prevent access of air; the wheels taking three or four days to cool, must necessarily cool equally, and this treatment prevents internal strain.

Sometimes large wheels are cast in a chill on the trod, and it is a fact worth noting that the chill is not destroyed by the annealing process, as no heat below that which the cast iron has when the particles taking the chill are solidified affects the peculiar hardness of the metal. There are certain objections to chilled wheels: they cannot always be cast of uniform diameter, and should the nave be bored out eccentrically much harm will ensue by the wheels wearing unequally. Besides, when such wheels are acted on by brakes, if care is not taken to prevent their locking, flat places may be formed on them by the brakes, which will prove very injurious, and the sliding action will also cause the chill to get soft. These wheels, however, are much cheaper than those fitted with iron or steel tyres, and have an advantage over the latter, inasmuch as when the line of railway is rough the cast-iron chilled wheels are not liable to become indented on the flanges, which sometimes takes place to such an extent with wrought-iron tyres as to endanger the safety of the engine. Wheels from 3½ to 4½ feet are sometimes cast in the plate or disc form, thereby lessening the tendency to fracture. The balance weight is cast along with the cast-iron wheels, whether the disc or radial-arm form is adopted.

Outside cranks.—When the axles are fitted with bearings placed outside of the wheels, with the wheels coupled together, wrought-iron cranks are fitted to the ends of the axles, having one large key way and two smaller ones for keeping the crank firmly on the axle. The crank pin is forged along with the main body of the crank; when six wheels are coupled together the width of the crank pin bearing for the middle crank is made in excess of the other two to allow for any lateral motion. The sides of the crank are quite straight from boss to boss; thus they are more easily planed, and at the same time the crank is much stronger. In other arrangements with inside bearings for the axles, the crank pin for the coupling rod is let into an eye bored out in a part forged on, or cast along with the nave of the wheel. The part fitting into the wheel is tapered and securely rivetted in. A set screw bearing on the side of the tapered part is screwed into a hole tapped through the eye, thus preventing the pin from turning; this can be done likewise with a short key let into the pin at the neck, which fits into a hole cut in the eye. On the end of the pin a collar is turned for keeping the rod in position, while others have a screwed part at the end, having a nut and washer bearing on the side of the brasses of the coupling rod. When the coupling rod takes the crank pin for the piston connecting rod, the former being next the wheel, the pin is enlarged over the others in order to strengthen the pin, as the overhang is considerable. In some examples the pins for the outside cranks are turned spherical, with the brasses in the rods bored out to suit, thus the rod swivels as it were with the motion, tending to throw less strain on the pins.

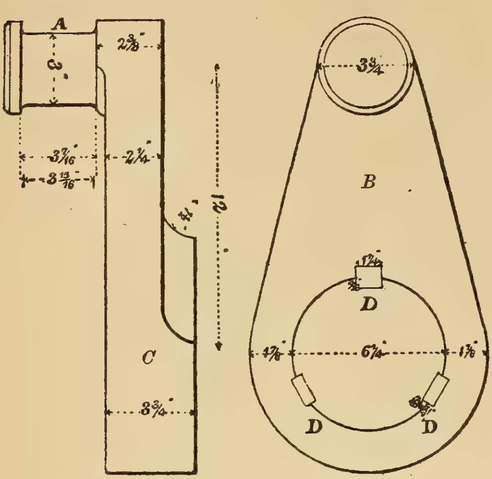


Fig. 502.—Outside Cranks.

A, Crank pin. B, Body of crank. C, Eye of crank. D D, Keys.

Framing and axle boxes.—The framing in all modern examples extends between the front or buffer beam and the back or draw beam, and is either double or single. With the former, suited for outside bearings, the frame was originally composed of two thin plates with wood between, held together with rivets, while the inside frame or horn plate was wholly of wrought iron.

When inside bearings are adopted the frame plate is of wrought iron, a plain parallel beam of considerable width and thickness, to which are fitted the horn plates for the axle boxes, but some have the horn plates and stays forged all in one piece. The framing is stiffened by the cylinders when placed between them at the front, the motion bar plate forms another source of stiffening, then comes a plate fitted between the frames in front of the fire box, while at the back of the fire box, plating is arranged for taking the drag links, and in some instances a casting is introduced, thus giving weight for adhesion in the hind wheels, and also strengthening the framing for taking the drag links, the pull and thrust being taken directly on the framing. Double frames are likewise made entirely of wrought iron.

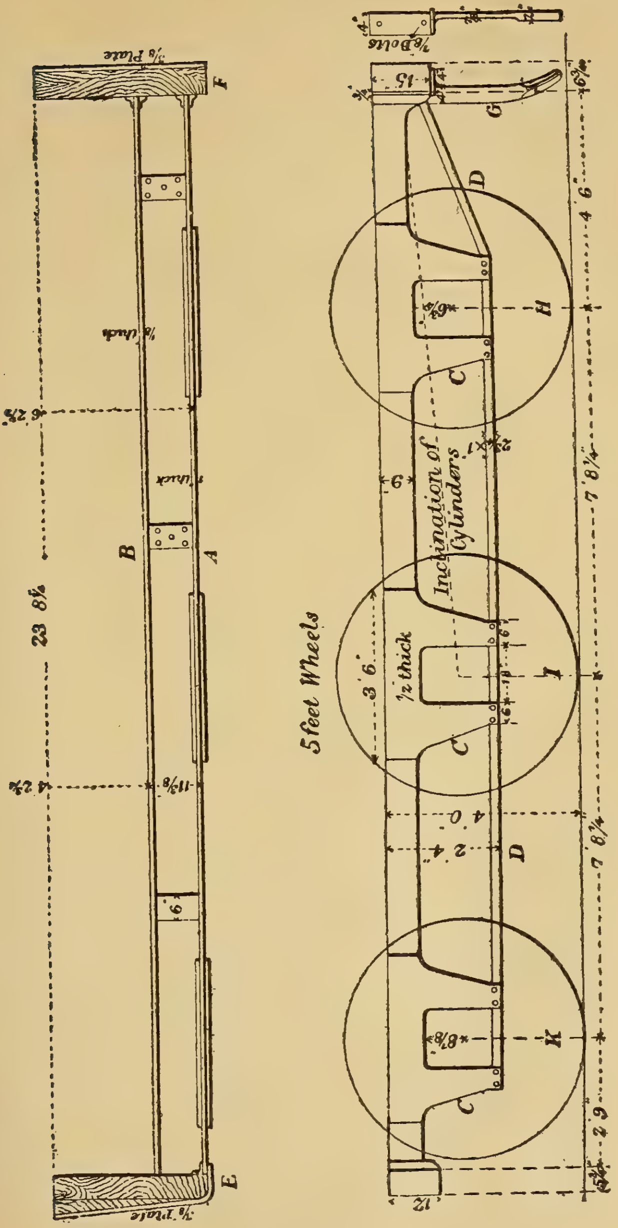


Fig. 503.—Plain Plate Framing.

A, Frame plate. B, Horn plate. C, Horn plates for the axle boxes. D D, Stays. E, Draw beam. F, Buffer beam. G, Guard. H, Leading wheels. I, Driving wheels. K, Trailing wheels.

The front beam for taking the compression strain, imparted through the buffers, is generally made of wood fitted directly to the frame ends, a flange being formed on the ends for bolting the beam to; sometimes a plate is introduced between the beam and the frame ends, an angle iron fastening being adopted to which it is firmly rivetted. The wooden beam in some cases extends the whole breadth across the light frame work and platform fitted on the top of the framing for passing round the engine, but it is preferable to end the beam at the longitudinal main framing, or otherwise bevel it from that point to each end; thus the blow imparted through the buffers is taken directly on the main framing, and cannot affect the light angle-iron frame for carrying the foot plates; moreover, the beam to a certain extent acts as spring beam for taking the shock. The draw hook and chain in front of the buffer beam, which is used when the engine is going backwards, is secured with an eye bolt passing through the buffer beam and plate, having a nut bearing on the plate.

The hind or draw beam is generally of wrought iron secured to flanges formed on the longitudinal frames; a framework of angle iron and plates is rivetted to the beam, spreading over a considerable space under the foot plate between the main frames to which it is securely rivetted; this framework carries the pin for the draw shackle, and consequently, as the whole strain of the engine comes on this part of the framing in the first instance, it requires to be strongly united to the longitudinal beams forming the main frame. In some instances a framework of cast iron has been adopted, carried from the draw beam forward to the back of the fire box. An angle piece is rivetted to the fire box; by this means the boiler is partly supported on the cast-iron framing, but in most instances the angle irons are rivetted to the sides of the fire box, taking an angle iron rivetted to the frame plates. The boiler has the power of expanding and contracting without straining the main framework, owing to the bolt holes in the angle iron being oblong, a very important matter to consider in the construction of the locomotive, for when the boiler is rigidly held with the framework without the power of expanding, rupture must eventually take place at some part, and more than likely in the body of the boiler. The other frame brackets for supporting the body of the boiler are formed by a continuation of the motion-bar plates, and at the front end the smoke box is secured to the main framing, the boiler expanding from that point quite independent of the framing.

When inside bearings for the cranked axle are used with outside bearings for the leading and trailing axles, both of the frame plates are in some examples made of wrought iron, having the horn plates or plates for taking the guides for the axle boxes forged on; the framing is stiffened with cross pieces between the two frame plates at each side, and likewise stiffened between the two inside ones.

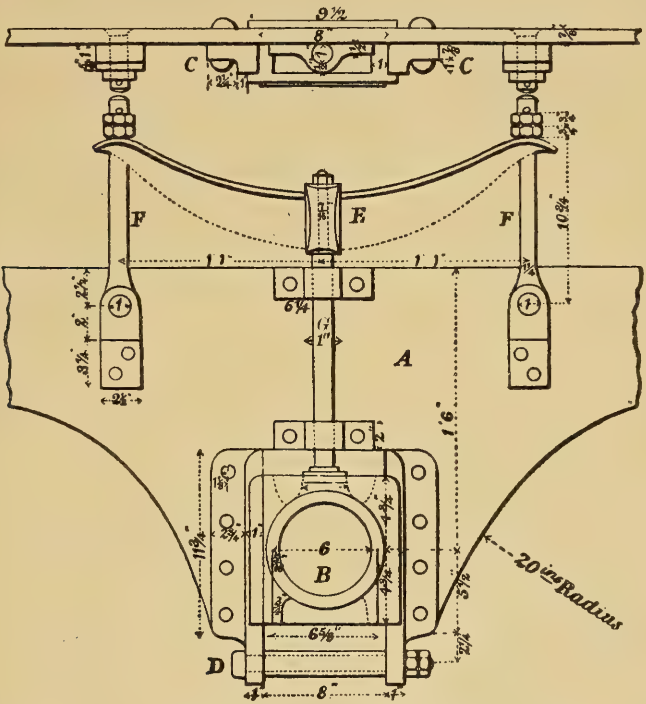


Fig. 504.—Inside Bearing and Horn Plate.

A, Inside horn plate. B, Axle box. C C, Guides for axle box. D, Hollow distance piece and bolt. E, Spring. F F, Spring harness. G, Spring pin.

The buffer beam is carried across as before, the compressive strain imparted through the buffers being in a more direct line with the outside frame plate, to which it is securely attached, as likewise to the inside frame, having a plate between the buffer beam and the end of the framing.

The back end or drag beam is fitted as before with plate and angle iron framing for taking the drag link, the framework being securely attached between the two inside frames.

When the driving and trailing axles have inside bearings, and the leading axle has outside bearings, double frames are used, and when the cylinders are placed outside, or between the two frames at each side, the outside frame is made of reduced thickness from the curved part of the horn plate at the top for taking the leading axle to the hind beam. In front of the driving wheel a plate joins the two side frames, to which the double-motion bars for the piston cross-head are firmly secured, as they are also to the cylinder cover.

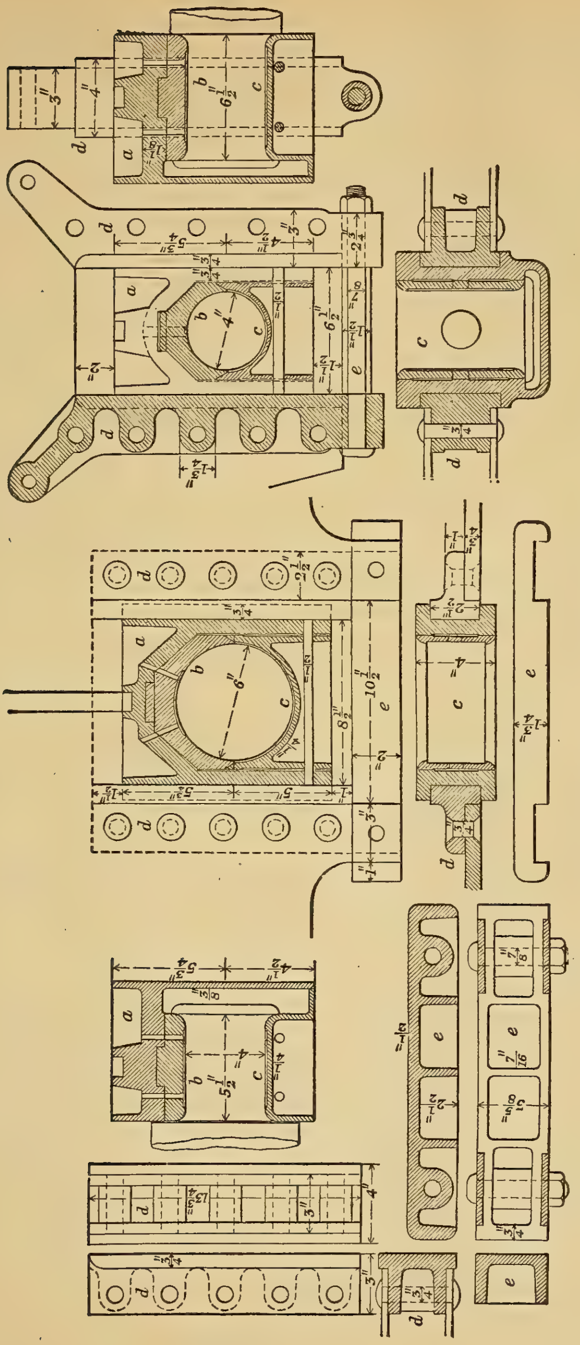
These double frames no doubt tend to make a much stronger framing, although it is not desirable, with outside-cylinder arrangements, to receive the shock of the buffer beam on the outside frame. Double wrought-iron plate framing is likewise used for inside-cylinder arrangements, having the driving and hind wheels coupled, the leading, driving, and trailing wheels being fitted with outside bearings, while an additional inside bearing in such cases must be used for the cranked axle, supporting it quite up to the sides of the crank throws.

Wrought-iron plate framing is now generally adopted for all classes of engines; when so fitted the hind or drag beam is sometimes made of wood, with an outside plate running across and bent in at the ends for taking the longitudinal beams, having a short plate interposed between the beam and the ends of the main framing, the part for taking the drag shackle being made of plate and angle iron, securely rivetted to the two inside frames and to the drag beam with angle irons, thus making a very secure attachment.

For outside-cylinder arrangements the side frames in some examples are connected together by one or more water tanks, of which they form the sides, the whole being framed on angle iron, with all joints rivetted and caulked the same way as a boiler. By this arrangement, the tanks being an integral part of the framing, great rigidity is secured. This principle is applicable to locomotives variously constructed as regards the number and position of the wheels.

It is customary with outside-cylinder arrangements to make the framing deeper at that part where the cylinders are attached, a hole being cut out in the frame for allowing the valve casing to pass through; some merely undercut the framing, while with inclined cylinders, flanges are cast on for bolting to one or both of the frame plates.

The axle guards, to which the guides for the axle boxes are bolted, are forged along with the frame plates, or in separate pieces,



Figs. 505, 506.—Axle Boxes, &c.

a, Axle box. *b*, Upper bush. *c*, Lower bush. *d*, Guides. *e*, Ties.

securely rivetted thereto. When the framing is composed of two thin plates, with a wooden beam between them, the guards are formed along with the frame plating; long guards so constructed require to be well stiffened by the axle-box guides, which in some instances are carried up between the plates into the timber, and securely bolted through and through the frame plates and timber. The guides are strengthened with flanges and bosses, having holes cast through, and are securely rivetted to the guard plates; they are also fitted with a distance piece and bolt underneath the axle box, thereby preventing the guard plates from springing; in other examples a tie bar with bolts is fitted to the guard plates. When a wrought-iron single frame plate is adopted with two guard plates rivetted thereto, guides of wrought iron are sometimes used of a T section, which are securely rivetted between the guard plates, the guards having a flat tie bar taking all the axles, and being inclined upwards at the end, taking the under side of the buffer beam. When the guard plates are forged along with the single frame plates the guide plates are of wrought or cast iron securely rivetted thereto, having a clip stay bar secured with bolts and nuts to the guard plates. In some cases both the guard and guide plates are forged along with the frame plate, thereby dispensing with rivetting, the guide plate having a distance piece with bolt passing through, with nut and jam nut, for securing the bolt. In others the guide plates are cast together, having sides and top piece, with a boss on the top, having a hole for the spring-bearing pin passing through. Sometimes one side of the guide plate is movable, with a wedge adjustment, so that the wear of the axle boxes, caused by the knocking action due to the working of the engine, can be adjusted.

The guide plates are planed on the surface and sides, and should be quite parallel. The guard plates are likewise planed on the edge, fitting accurately against the guide plates, which are likewise planed on the part the guard plates fit against. In fitting up the guide plates they should be screwed hard up against the guard plates, and then all the rivet holes made fair prior to rivetting up.

The axle boxes are of cast iron with brass bushes; flanges are cast on each side of the box, which bear on the sides of the guide plates, thus guiding the axle box vertically; the working sides of the axle boxes and flanges are planed, bearing against the planed surface of the guide plates. With the springs placed above the axle box, the whole weight is taken on the top, the spring-bearing pin resting on the cast iron, a boss with a part cast out or bored out being left on, forming a step for the end of the pin. The sides of the axle boxes are from ¾ to 1 inch in thickness; but when the springs are underneath the axle boxes the sides require to be much thicker, as the weight is taken through the sides. A wrought-iron strap has been used to strengthen the axle boxes; the strap is bent over the box, passing down on each side, the pin for taking the spring shackle passing through the strap. Wrought-iron axle boxes have been used; they are of course much stronger, but they do not wear so well as the cast-iron ones; solid brass, and Muntz metal axle boxes have likewise been adopted for underhung spring arrangements, the brass sides being 1½ inch in thickness, but of course they can be made much thinner, when a wrought-iron strap is likewise used.

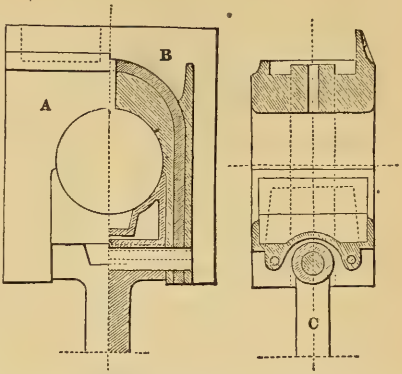
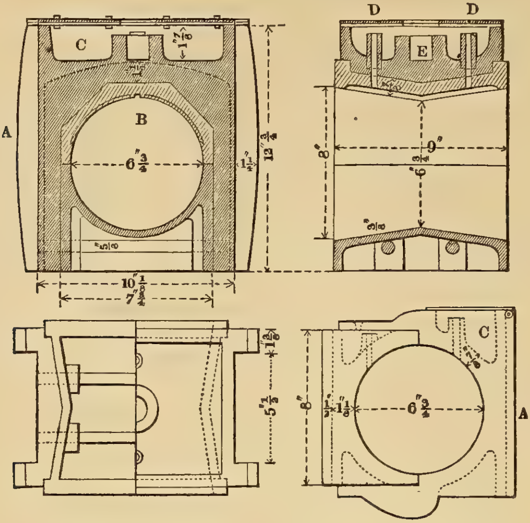


Fig. 507.—Brass Axle Box with Wrought-iron Strap.
A, Axle box. B, Strap. C, Shackle.

The brass bushes for the axle boxes are quite circular, bored out parallel in some, while in other arrangements the bearing tapers from the centre, where it is small, to a larger diameter at the sides, the journal being made accordingly. The bush should be well fitted into the axle box at the top and sides; it is preferable that the top surface should bear all over, but the sides may have fitting strips, thus lessening the labour in fitting up. Flanges for holding the bush in its place are cast along with the top bush, and are likewise accurately fitted into the axle box. The bottom bush is a mere shell of cast iron, fitted into the bottom part of the axle box, and is held in position with two pins, passing through the sides of the axle box and bush. The top part of the axle box must be made of considerable thickness for taking the weight imparted through the springs; it is formed with a circular seat for the spring pin, but sometimes two spring pins are used of a flat section. The sides of the axle box project above the crown, forming a grease cup for the tallow and oil used in lubricating the journals. The bush for the journals should be bored out about $\frac{1}{16}$th of an inch larger than the journal, as they are not so liable to heat when made a little slack in the first instance. The grease chambers should be fitted with two siphon tubes, which are screwed into the top part of the axle box, and provided with cotton wicks, the wicks insuring by capillary action a constant and steady flow of oil, or other fluid lubricant; holes are bored through the bushes, and grooves are cut from hole to hole in the brass, thus allowing the oil to flow along the top part of the journal. Sometimes the grooves have been cut diagonally from each hole; this plan is not so good as the former, as the oil runs greatly to waste; whereas, when a groove is cut in the brass along the top, the lubricant flows on the top of the journal, where it is most required.



Outside Driving Axle Box. Inside Driving Axle Box.

Figs. 508, 509.—Axle Boxes with Tapered Bearing.

A, Axle box. B, Brasses. C, Oil cup. D D, Holes for siphon wicks. E, Boss and hole for spring pin.

Sometimes a separate oil chamber is cast on the top of the axle box, provided with a cover, and siphon tubes and wicks; and for the leading and trailing axles, with the wheels uncoupled, the axle box has an outside plate cast along with it, which prevents dust and grit from destroying the surface of the journal. In some arrangements the lubricating cup can be removed through the hinged cover at the end, while the under shell is so constructed as to catch the waste oil, thus providing a very efficient mode of lubricating the journal, the pin for the spring bearing upon the top of the chamber, where the oil cup is placed. Sometimes the axle boxes for the driving axle are fitted with wedge pieces between the flanges, one on each side, acting as guide plates, but adjustable at pleasure, these wedge pieces sliding on guides which are rivetted to the frames. At the top and narrow end of the wedge a round part is forged on, turned, and cut with a screwed thread, which, passing through a hole in a bracket rivetted to the frame, the wedges are adjusted and held in position with a nut bearing on the top and bottom of the bracket. In another arrangement a single wedge is adopted on one side, while the other side of the axle box has a plain guide; the wedge piece is the entire breadth between the flanges, and is drawn up with a screwed part, which is forged along with the wedge as in the preceding example. In Figs. 512 and 512A is an arrangement of adjusting wedge and axle box fitted to

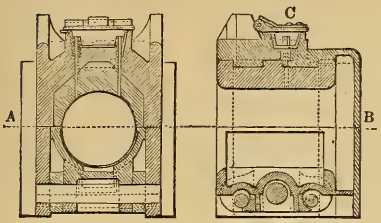


Fig. 510.—Axle Box with Covering Plate.
A, Axle box. B, Plate cast on. C, Oil cup.

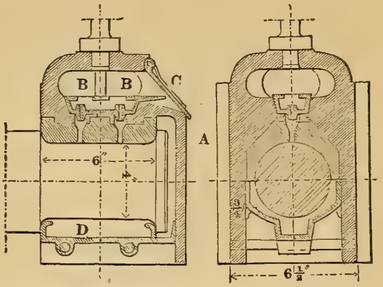


Fig. 511.—Axle Box with separate Oil Cups, &c.
A, Axle box. B, Oil cup. C, Hinged cover.
D, Recess at bottom.

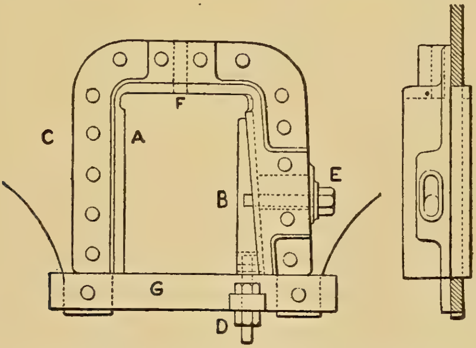


Fig. 512.—Guide for Axle Box with Wedge Adjustment.
A, Axle-box guide. B, Wedge. C, Horn plate. D, Adjusting bolt. E, Set screw. F, Hole for the spring pin. G, Tie bar.

more recent engines. The guide is made all in one piece, and securely rivetted to the horn plate. The adjusting bolt for the wedge is at the bottom, the nuts bearing on the part forged on the tie bar, while the adjusting bolt passes through a slot formed on the guide. This example of wedge pieces is fitted by some makers to the back of all coupled axles. The inside bearing used for cranked axles, when fitted with bearings outside of the wheels, is likewise fitted with wedges in some examples, one on each side of the horn bar, having the guides forged thereon. The wedges are cut with a groove which works in a feather on the guide pieces. The tightening parts are forged on and cut with a thread, and are longer than in the previous examples, passing up through elongated holes on the top of the horn bar, having a nut and a jam nut for each wedge. The jaws of the guide pieces have a long ferrule at the bottom, with a bolt passing through, to prevent the jaws springing.

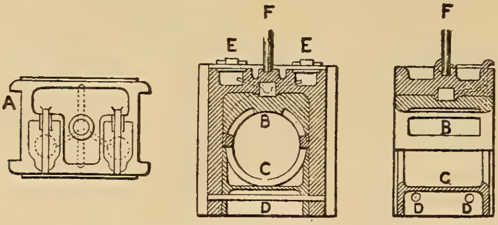


Fig. 512A.—A, Axle box. B, Top bush. C, Bottom. D D, Pins for securing the bottom part. E E, Oil cups. F, Spring pin.

Springs and harness.—Springs are flexible beams, composed of thin steel plates, loaded at the middle, and free to move at the ends. Ordinary springs are much deeper at the middle than at the ends. This is required to obtain uniform flexibility throughout, the plates decreasing in length towards the centre. Every part of a spring should yield equally throughout. If any part of a spring is more rigid than another part, it is between those parts that the spring will give way, simply because the portion that is the most flexible will become unduly strained. Springs that are properly constructed, and loaded within the limits of their capacity for carrying weight, deflect through equal spaces for equal additions of weight applied, when the span is sensibly constant When the compass of a spring is considerable the span or length of the spring must increase with the weight applied. The elastic strength of a spring is measured by the weight necessary to cause a given deflection, and *vice versa.*

The strength is measured by the greatest weight the spring can carry without giving way; when over-weighted, the symptoms of rupture consist in the greater apparent elasticity of the spring, or a greater deflection under a given increase of weight, independently of what may be due to an increase of length or span. That point at which a decided change takes place is an index to the strength of the spring. Ordinary springs, when loaded, are 2 feet 8 inches from centre to centre, and when unloaded, 2 feet 7¼ inches from centre to centre, and have a set of 5¼ inches from the point of suspension to the top of the plates; the breadth of the plates is usually 4 inches.

The following table illustrates the constancy of the elasticity for sensibly equal spans, and its slight increase as the weight carried is increased is due to the increase of span:—

DEFLECTION UNDER GIVEN LOADS.—Span in working order, 30 inches.
2 plates of $\frac{3}{8}$ inch in thickness; 14 plates of $\frac{5}{16}$ inch in thickness—16 in all, 4 in. broad.

Loads.	Compass Measured to the Centre of Suspension.	Total Deflection.	Span Measured to the Centre of Suspension.
cwts.	inches.	inches.	inches.
0	$5\frac{5}{8}$ full.	0	$28\frac{3}{4}$
35	$5\frac{5}{16}$	$\frac{5}{16}$	$29\frac{3}{16}$
40	$5\frac{3}{16}$	$\frac{7}{16}$	$29\frac{5}{16}$
45	$5\frac{1}{16}$ full.	$\frac{1}{2}$ full.	$29\frac{3}{8}$
50	5 full.	$\frac{5}{8}$	$29\frac{7}{16}$
55	$4\frac{15}{16}$	$\frac{11}{16}$ full.	$29\frac{1}{2}$
60	$4\frac{7}{8}$ bare.	$\frac{13}{16}$	$29\frac{9}{16}$
65	$4\frac{3}{4}$ full.	$\frac{7}{8}$	$29\frac{11}{16}$ bare.
70	$4\frac{11}{16}$ full.	$\frac{15}{16}$	$29\frac{11}{16}$ full.
75	$4\frac{5}{8}$	1 full.	$29\frac{3}{4}$
80	$4\frac{9}{16}$ bare.	$1\frac{1}{16}$ full.	$29\frac{13}{16}$
85	$4\frac{7}{16}$ full.	$1\frac{2}{16}$	$29\frac{7}{8}$
90	$4\frac{3}{8}$ full.	$1\frac{1}{4}$	30
95	$4\frac{5}{16}$	$1\frac{5}{16}$	30 full.
100	$4\frac{1}{4}$	$1\frac{3}{8}$	$30\frac{1}{16}$
after shaking lever.	$4\frac{1}{8}$	$1\frac{1}{2}$ ($\frac{1}{8}$ set).	$30\frac{1}{8}$ full.

It will be found that the flexibility is increased 2·6 times when the span is a trifle over 30 inches. This extension is entirely due to the weight applied and to the great compass of the spring. The elastic strength of a spring is one thing, and its elasticity when unduly loaded is another. The strength varies as the span or length between the supports inversely, as the depth or number of plates directly, as the square of the thickness of the plates, and as the breadth of the plates; while the elasticity varies as the cube of the span, as the depth or number of plates inversely, and as the breadth of the plates.

The flexibility of the engine springs varies in practice from ¼ to 1 inch per ton of load, and in some is even as low as ⅛ of an inch. Springs should be easy of action, and should be more or less flexible to meet the requirements. The springs fitted to the axle boxes of the leading wheels should generally have the least flexibility, as from the severe strain due to the irregularities of motion of the engine, and imperfections in the permanent way, their springs are very severely tested. In a six-wheeled engine, having the centre wheels as the drivers, the springs fitted to the driving axle boxes should be made of great elasticity, so that the wheels have always a grip on the rails, maintaining the full tractive load as equally as possible; more especially as the load on the driving wheels being the greatest the rails may yield with the weight, and partially lose a portion of adhesion or traction due to more weight being thrown on to the hind spring. The latter should be of great flexibility, so as to yield to the driving springs when the wheels sink from unevenness or sinking of the rails. At the same time the hind springs should be of sufficient elastic strength to steady the motion of the engine. In engines having the hind wheels coupled to the drivers, the springs may have an elasticity of ½ an inch per ton of load. For engines much overhung either before or behind ¼ of an inch per ton should be allowed for the elasticity of the springs. If the overhang be behind it should be reduced to ⅛ of an inch per ton of load; and in six-wheeled coupled engines, running at low speed, the flexibility need not be more than ¼ or $\frac{5}{16}$ of an inch per ton of load.

The springs most commonly adopted consist of steel plates in close contact with each other for their entire length, with wrought-iron eyes forged at the ends of the top plate, to which the links are secured with a pin passing through a hole bored in the eye. This form of spring from long practical use has been found to answer all the requirements. In some places where there is not much ventilation, and a good deal of moisture, as in the draw springs underneath the framing, close plated springs are not so good as open springs, owing to moisture getting in between the plates, which soon become rusty and stiff, and cease to act in a satisfactory manner. The plates of the springs are kept fair with each other sideways by studs punched up at the ends of each plate, entering and sliding in slots in the plate adjacent. Modern springs have a longer part punched in a similar way, fitting into a hollow in the plate adjacent; this ridge and furrow gives greater strength for preventing the plates moving either longways or sideways. The plates are likewise held in position with a wrought-iron hoop shrunk on at the middle, binding the whole together, and fitted with a boss and hole to take the end of the spring pin, which bears on the axle box. The springs are arranged above the axle in some cases and below the axle in others, there being independent springs for each axle box; while in others the trailing wheels are sometimes fitted with one spring for both axle boxes, arranged across the engine below the foot plate. The springs are generally fitted with scroll or solid ends for taking the links and pins, and in some flat ends are adopted.

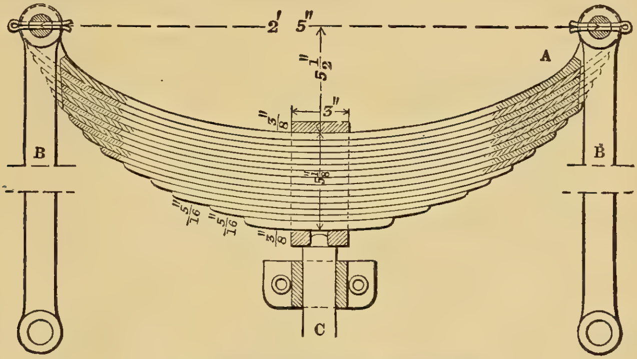


Fig. 513.—Spring with Plain Link Harness.
A, Spring. B B, Harness. C, Spring pin.

The most simple description of spring harness has one link let into jaws formed on the solid ends of the plates, with a pin passing through the eyes formed on the top plate, the bottom end of the link being secured to the framework with a pin, supported with a bracket rivetted to the frame. All these pins should be fitted with a washer at the end, and a split pin passing through the main pin. Another plan adopted for single wrought-iron frame plates has two links, one on each side, with a raised boss at the bottom end, the top and bottom being secured with a pin taking the links and the spring at the top, and another the links and frame at the bottom end. The spring pin for taking the thrust on the top of the axle box is round in some, with a reduced part turned at the top, which fits into a hole bored in the central hoop, and sometimes passing through the spring and hoop, and secured with a nut at the top. In others, the spring pins are of a flat section, having two pins for each spring, one on each side of the frame. These are guided by means of a wrought-iron bracket rivetted to the frame, with holes bored to suit the round pins, and a flat part formed in the bracket for the flat pins, the bottom end of the pin resting in a part formed on the top of the axle box. In other forms of spring harness adopted for solid eyes, formed on the top plates, the links are made with a clip piece at the top embracing the eye, thus no pins are required, the weight being taken directly on the clips.

When plain links and pins are adopted the spring, when once set, cannot be altered; this is the only inconvenience attending so simple an arrangement. It is considered, however, in many examples that the spring harness should be so constructed that the spring can be tightened up, as it were, or slackened at pleasure. With that object in view a box form of link has been adopted, made with jaws for taking the spring ends; the bottom part of the link is different, being made with an eye and pin for passing through the framing. It is likewise screwed for part of its length, having a nut which bears on the bottom part of the top piece by simply turning the nut, when the weight is on the spring. It can be shortened or lengthened as required, by this means adjusting the spring to the greatest nicety.

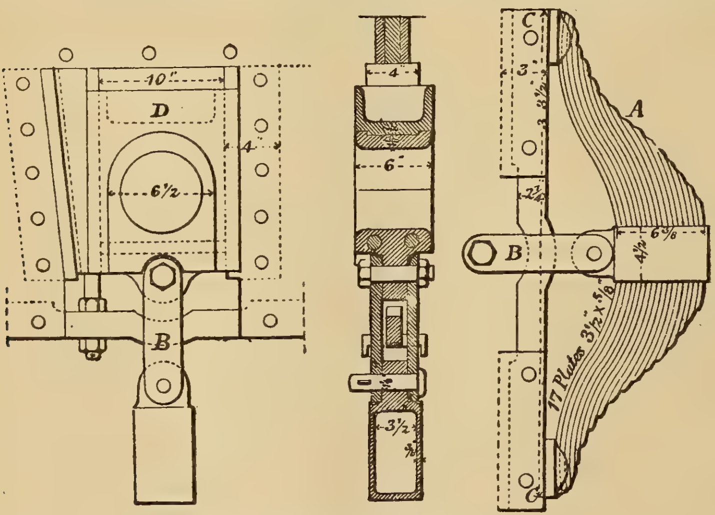


Fig. 514.—Flat-ended-Spring and Harness.

A, Spring. B, Shackle. C C, Shoes. D, Axle box.

When the springs are flattened at the end the link is simply a round bar, with an eye and pin for the bottom end, and a raised screwed part for the top end, which passes through an elongated hole in the ends of the spring, the spring being adjusted with a nut on the top, having a jam nut and split pin passing through the end of the link, and in some a simple strap is indented in the ends, with a pin for securing the strap to the framing. When flat-ended springs are arranged underneath the axle (Fig. 514), the spring is connected to the axle box with two side links and pins, taking a snug on the central hoop on the spring; a snug is likewise cast on the bottom half of the axle box bush, which is made of extra strength to take the strain. Shoes are fitted to the frame or horn plates, having projecting flanges to prevent the spring moving sideways.

When transverse springs are adopted the spring harness is arranged at the middle, the spring working in some cases between the transverse plates, which are rivetted to the framing, and the spring is set up with a single nut and screwed piece forged along with the central hoop. Volute springs have been used for the hind axles; the vertical pin for taking the thrust on the axle box has a plate at the top, recessed for two volute springs, one on each side on the top of the springs; another plate is placed so as to bear on the small flat end of the springs; a bolt passes through each end down the centre of the springs, and through the bottom plate, these bolts passing through holes in brackets which are rivetted to the main frame; the bolts are screwed at the bottom, and the springs are adjusted with a nut and jam nut on each. The thrust pin should be guided with a bracket, placed quite close to the under side of the bottom plate. These springs certainly occupy less space, but we prefer flat curved

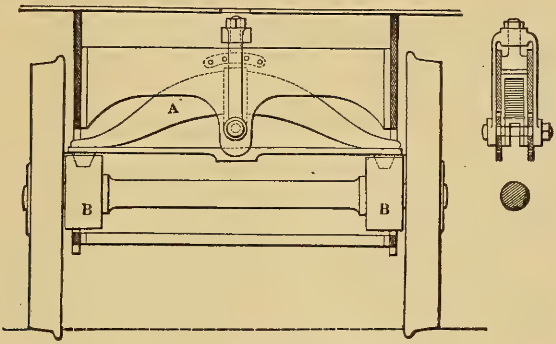


Fig. 515.—Transverse Spring.

A, Spring. B B, Axle boxes.

springs as usually constructed, as their action is easy, and better calculated in every respect to meet the requirements. India-rubber springs have been tried, but have proved a complete failure, as they get crushed, and at times settle into a rigid mass; moreover they are very quick in action, and are very destructive to the machinery and permanent way; in summer, also, they get soft, and in winter hard, and should oil get near them they deteriorate rapidly.

Compensating levers.—To make the action of the springs more perfect, they are coupled together in some instances with compensating levers. Thus the loads on the springs are equilibrated, as any deflection in either spring from the motion of the engine and imperfections in the permanent way is transmitted to the other spring. The compensating lever is underneath the framing, and may be arranged with a long and short end, or with the fulcrum in the middle of the lever. In some arrangements the leading and driving springs are so fitted, while in others the driving and trailing springs are coupled to the lever, while others have only springs fitted to the driving axles, the elasticity of the hind bearing being transmitted from the driving spring through the compensating lever, which is directly attached to the hind axle box with a link connection, as shown in the American style of trussed framing.

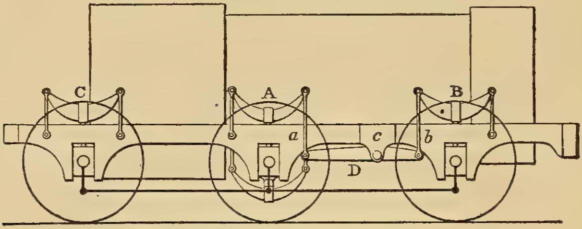
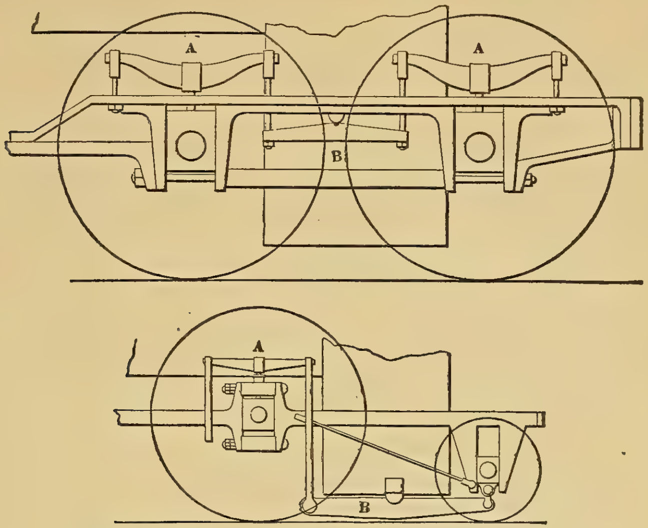


Fig. 516.—Compensating Lever.

A B C, Springs. D, Compensating lever. *a b*, Links joining lever. *c*, Fulcrum of lever.

When there is a moderate distance between the wheels, the centres being say 5 feet and under apart, a single spring is placed between the wheels, located on the top of the framing, as shown in Fig. 518, fitted to the bogie in front (Fig. 519). In this arrangement the spring itself is the compensating lever. The concussion from the wheels is taken directly on the ends of the spring, while the deflection at one end is transmitted to the other axle through the spring itself, the mechanism thus being simplified, while the action is more perfect. For a greater distance between the centres of the wheels a lever of the same span as the wheel centres is introduced, with pins bearing directly on the axle boxes. The ends of the spring are linked to the framing,



Figs. 517, 518.—American Methods of Coupling the Springs.

A A, Springs. B B, Compensating levers.

while the butt of the spring is supported by the lever; thus equal loads are put on the axles. In some cases the springs are inverted,

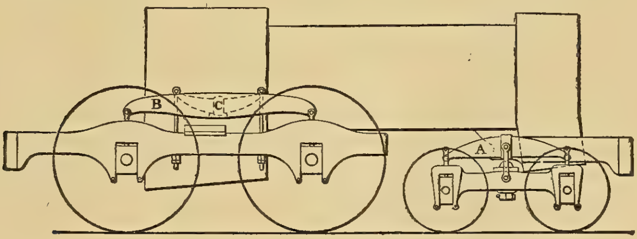


Fig. 519.—Inverted Spring and Compensating Lever.

A, Inverted spring on bogie. B, Compensating lever. C, Spring.

butting against the frame, and connected with links to the compensating beams, the latter being jointed to the axle boxes. The action is very easy, insuring a constant load on all the axles, but at the same time it confines the spring base to one half of the wheel base, which is injurious from the overhanging parts at each end. Various other arrangements may be adopted; and sometimes the link is fitted with india-rubber washers, placed between two metallic ones butting against a swivelling piece, which is fitted to a jaw formed at each end of the compensating lever, having a nut on the link for adjusting the load; these india-rubber washers tend to soften the action; the other links are fitted likewise with washers bearing on the under side of the frame.

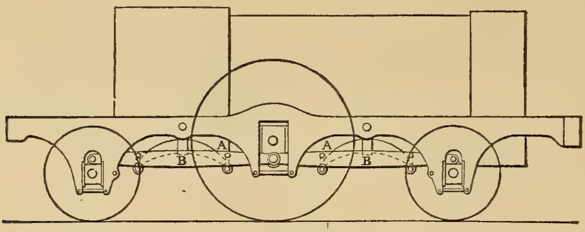


Fig. 520.—Inverted Springs and Compensating Levers.

A A, Springs. B B, Compensating levers.

Bogie carriage.—The bogie carriage is introduced in front of the engine to assist or ease the rubbing of the flanges of the wheels against the rails in rounding sharp curves. It is placed underneath the main framing, and is entirely separate from it, being free to move on a central axis either way. In some six-wheeled engines the centre or driving wheels are left without flanges, with the same object in view, while in all engines the flanges for the centre wheels are reduced in thickness, or, in other words, have more clearance from the side of the rails. If the flanges were to grip the rails, the strain on the framing would be very severe, and when the curve is very sharp the engine might be thrown off the rails. The object of the bogie carriage is to prevent this. It provides a long wheel base, combining the advantage of an ordinary eight-wheeled engine as used for comparatively straight lines of railway, with the advantage of a short wheel base, when the curves are very sharp. In fact, the front bogie may be swivelling into a sharp curve while the driving and hind wheels are on a straight part of the line, as when crossing from one line of rails to the other line at the points. The bogie carriage is a frame of wrought iron carried on four wheels, with springs and axle boxes as in ordinary frames; two plates on edge pass transversely between the side frames, and are trussed with plates from the corners. At the centre of the bogie, where the tie plates radiate from, a circular boss is formed, which is bored out for taking a ball, thus forming a universal ball-and-socket joint, the ball being securely fastened with plate brackets to the under side of the boiler, and having a projection forged on, with screwed part and nut bearing on the under side of the bogie frame; this pin has sufficient clearance in the hole to suit the inclination of the bogie frame in either direction. The frame, being pivoted on a ball, can more easily move in any direction. In this form of bogie the front part of the engine is entirely supported

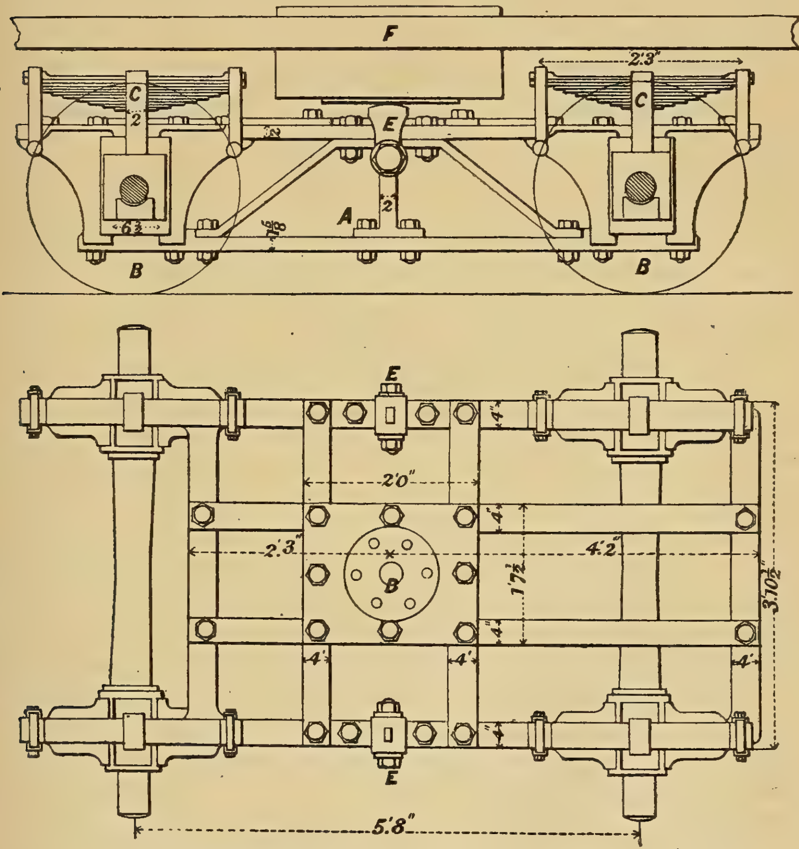


Fig. 521.—Bogie Carriage. — A, Bogie frame. B B, Wheels. C C, Springs. D, Centre of motion. E E, Sliding pieces. F, Engine frame.

on the ball. In some of the centre bearing description the ball is dispensed with, and the load carried upon a broad flat circular seat; others rotate on a pin with side sliding pieces fitted on the top of the bogie frame, corresponding pieces being fitted to the main framing of the engine, or to the carrying plate, so that the bogie can move transversely and radially, while some sliding pieces are cast along with the cylinder, and strongly bracketed in the casting, and secured to the under side of the smoke box. These side sliding pieces are quite flat in some cases, and in others are formed on an obtuse wedge or double incline for the transverse motion of the bogie; the front part of the engine lifting, as it were, when the bogie is striking a curve, the bogie being free to move 1½ inch either way or rather sideways, and sinking into the flat V-shaped piece when on a straight part of the line. It is evident with this form of sliding side piece, that the friction must be very great, and it is simply introduced to maintain the bogie in an even line with the other wheels when on a straight part of the line of railway. In some modern examples (Fig. 521), mostly applied to American engines, the curves on some of the American railways being very quick, the sliding pieces, fitted to the main framing of the engine, rest on a segmental roller fitted to the bogie frame on each side, the axis of this roller being secured to the frame; with this provision the swivelling action is very easy. Stops are generally fitted to prevent the bogie turning round too far.

Buffers, couplings, rail guards, sand boxes, &c.—The buffers, fitted to the front beam or buffer beam of ordinary engines, and likewise to the front and hind beams of tank engines, are of the metallic description, consisting of a volute spring placed in a cylindrical box bolted to the frame, having a telescopic piece cast with a flange, and fitted with a wooden buffing piece. The spring has a bolt passing through, taking the telescope piece and cylindrical box, thus holding the spring and telescope piece in position; in the act of buffing the spring is compressed, while the telescopic piece slides in the box, sufficient clearance at the end being left to suit the range of the spring. These springs are in some examples fitted between the engine and tender.

The engine is coupled to the tender with a rigid connection in some cases and an elastic connection in others. With the former a right and left-hand screw, having a bar for tightening up, is used; each screw passes through a nut, fitted with journals, taking a link, which is secured by a bolt passing through brackets on the engine and tender beams; the bolts are prevented from lifting by means of split cotters bearing on the under side of the brackets. The engine beam is fitted with a cast-iron block having a convex surface, and on the tender beam a block is fitted with a concave surface, both of the blocks being rounded vertically; by this means they are enabled to take the vertical and swivelling motion of the engine and tender, the blocks being drawn into juxtaposition with the right and left hand screw. The tender is sometimes fitted with buffers, as on the front of the engine, to steady the motion of the engine and tender; and side-chain couplings are fitted in case of accident to the coupling, thus preventing the engine getting detached from the train; in some instances plain long links are substituted.

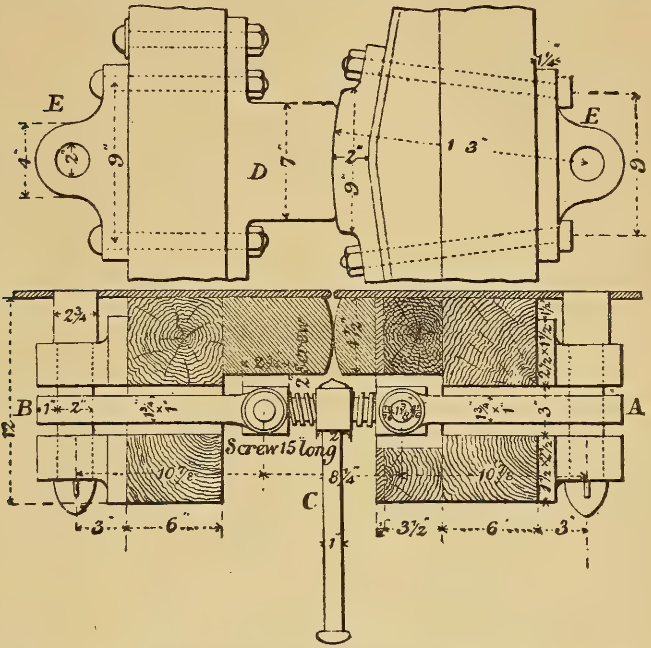


Fig. 522.—Coupling between Engine and Tender.

A, Shackle and bolt on the engine beam. B, Shackle and bolt on the tender beam. C, Right and left hand screw and handle. D, Block pieces. E E, Brackets for draw pins.

In other arrangements the draw link is connected to a transverse spring, which is extended as the strain or pull comes on it; with this method the engine is drawn away from the solid buffing pieces, and when the engine is suddenly reversed, as is the case at times, a violent shock between the engine and tender is the result. There can be no doubt that a rigid connection between the engine and tender is to be preferred, the pull between these being solid and inelastic, and side buffing springs being only used to steady the motion.

Another arrangement of draw gear consists of a plain bar, which is connected to the engine by an elongated eye, and to the tender and spring shackle by a plain eye; the transverse spring is fitted with rods having buffing pieces at the flat ends, the rods passing loosely through bosses on the tender end beam; thus when the engine and tender are drawn together a slight compression is given to the spring through the buffing pieces, and the pin for the draw shackle is then dropped into its place. This arrangement is rigid when the engine is running, and when the engine is reversed the shock is taken on the spring ends, the elongated slot on the draw bar allowing for the compression. The safety chains, one on each side, are simply single bars with an elongated eye for the engine end, and a plain eye for taking the pin on the tender frame. This plan of draw gear is a decided improvement on the foregoing example, as the shock while reversing the engine is easy, and not at all destructive to the machine; at the same time, when the engine is suddenly reversed backwards and then instantly put forwards the strain must be rather severe, so on the whole we prefer the rigid connection, which remains so when the engine is going either way.

The draw bar and hook for tank engines are fitted with an india-rubber spring, which is placed in a box secured to a wrought-iron frame underneath the foot plate, the draw bar having a flange bearing on the india-rubber, and secured to the rod with a cotter. The spring, in some examples, is contained within a wrought-iron shackle, having a round piece forged on for taking the spring, with a central hole for the draw bar passing through. The shackle is held by means of a round pin passing through a hole in the framework underneath the foot plate. A shoulder is left at the hook outside of the draw end or beam, and the draw bar is tightened up against it with a nut bearing on a washer, which compresses the spring; by this means the rod and shackle are made quite rigid, or, as it were, drawn taut by the action of the spring. The draw chain in front of the engine is likewise fitted with an india-rubber spring, which is contained in a box bolted to the inside of the buffer beams, the draw bolt being fitted with a loose washer and nut for adjusting the draw gear.

The rail guards are placed in front of the leading wheels, and within a few inches of the rails; they are intended to push aside any obstruction, such as large stones that may fall from deep cuttings, upon the rails. The guards are made of wrought iron, and are bolted to the framing, and in some cases to the buffing beam. In no case should they form part of the framing. As the obstruction may be heavy and bend or even break the guard in the act of displacing it, we are inclined to think that the buffing beam is the proper place to fix the guard, as the strain in displacing a heavy stone or other obstruction would be confined to the wooden beam, which could be easily replaced were it injured; whereas were the main framing of the engine strained with the impact of the blow imparted through the guard in displacing the obstruction, it would entail heavy repairs. A thin scraper or brush is attached to the guard to clear snow off the rails. It has been proposed that the sheet-iron scraper should be acted on by the springs, but this is an unnecessary refinement, seeing that a snow plough in many instances is required to clear the track. The thin scraper can only be of use to keep the top of the rails free from snow, thus preventing the leading wheels crushing the snow into a solid cake, on which the driving wheels would slip.

Sand boxes are fitted to the framing of the engine, with a pipe descending to within a few inches of the rails. This pipe should be bent at the bottom backwards, so that the sand may be allowed to drop gently on the top of the rails, and so get them properly covered. Sand boxes are generally made too small, owing, we have no doubt, to their unsightly appearance, as fitted to the framing. In some cases large sand boxes have been placed on the top of the boiler, with a pipe descending on each side, so that with one valve or tap the rails on each side are sanded simultaneously. The regulating valve is generally of the disc description, with two apertures for allowing the sand to pass through, the valve being fitted with a spindle, lever, and rod, passing along to the platform. In order to obtain sufficient bite for the wheels, the rails being in a greasy condition, the sand must be clean and sharp; moist sand will not do, so to free it from moisture and obtain a hard gritty powder it must be roasted. A good plan for doing so is by baking it in a fire-brick oven. In most railway-locomotive workshops a furnace is kept burning, named the "kindling furnace," where at any moment the stoker can get a shovelful of live coal to kindle the fire in the locomotive fire box, and the sand for the rails used to be roasted on a griddle of cast iron placed over this kindling furnace, but the frequent cracking and breaking of the plate gave a deal of trouble, as the sand fell into the fire. The roasting oven should be made entirely of fire-brick; it is arched over the fire, the flame passing through flues all round the oven, and then up the chimney. The door of the furnace is made of cast iron, lined with firebrick, and fitted with a chain and balance, the chain passing over suitable pulleys. As the whole of the brickwork gets intensely hot, it is necessary to bind the building with angle iron round the edges, secured with cast-iron girders, with bolts at top and bottom running across the brickwork; in this way the brickwork is prevented from cracking.

Foot plates should be of a ribbed or checkered pattern to give a secure foothold, the plates being 3/8 of an inch or so in thickness behind the fire box, and 1/4 of an inch in thickness all round the top of the framework. The plates are secured to angle iron forming part of the framing, or supported by brackets bolted to the frame, and edged with angle iron, the foot plates and angle iron forming the fender when no outside framing is used.

The foot space for the engine-man and stoker at the back of the fire box is protected with thin sheet iron, supported by wrought-iron pillars and rail, the pillars being secured to the framing. There should in all cases be fitted a weather-protecting plate, covered in at the sides and top so as thoroughly to protect the driver and stoker, the plate being fitted with two round windows for looking ahead. Indeed we consider that a *cab* should be fitted on all engines in all countries, similar to those on the American engines; but of course, for very warm climates, the protection should be freely ventilated, or be, as it were, an open *cab*, consisting of wrought-iron pillars, and top awning to protect the head from the vertical rays of the sun. Hand rails should be fitted all round the framing at the sides and front, formed of wrought iron, secured to the boiler with round eye studs, screwed into a plate with boss piece, which is rivetted to the boiler.

Two iron steps are generally fitted to the framing for ascending the foot plate at the fire-box end, and front steps may be fitted when necessary, so as to facilitate the inspection of the machine.

Splashers are fitted on the top of the framing, inclosing the wheels, which they should do effectually, so that there will be no danger when passing along the foot plates when the engine is running at a high velocity. They are formed of thin plates and angle irons, with angle-iron flanges for securing them to the framing; they are generally edged with strips, and should be constructed in a tasteful manner. Of course the top of the arch should be kept sufficiently clear from the flange of the wheel to allow for the action of the springs. Some ornament these parts with bright brass work, we certainly prefer tasteful painting, as the brass work requires constant cleaning to keep the machine nice looking.

Feed pumps and feed-water apparatus.—Feed pumps, as applied to the locomotive, are of three descriptions, namely, long-stroke ram pumps, worked from the piston crosshead; short-stroke ram pumps, driven with an eccentric; and independent steam pumps, having a small engine expressly for the purpose of supplying water to the boiler; while the feed apparatus consists of the much-used *injector.*

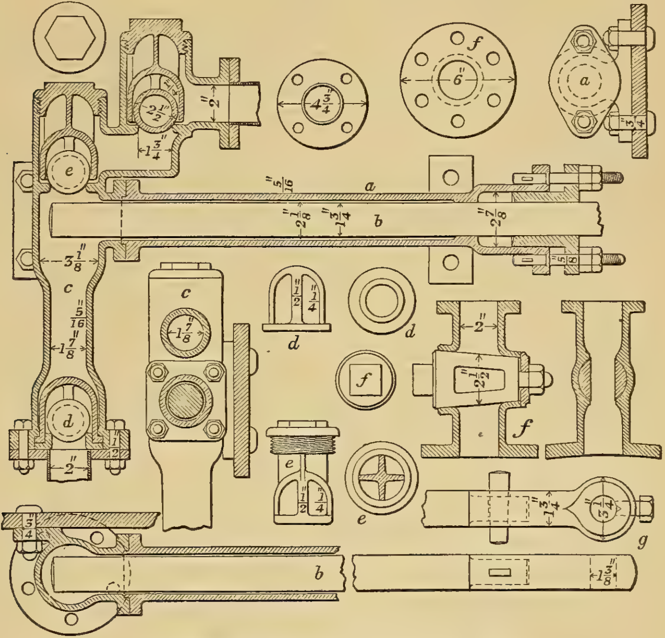


Fig. 523.—Feed Pump and Valve Chests of Brass.

a, Working chamber. *b*, Plunger. *c*, Valve chambers. *d*, Suction valve.
e, Delivery and non-return valves. *f*, Stop plug tap on boiler. *g*, Eye piece on end of plunger.

When long-stroke pumps can conveniently be applied they are to be preferred, no matter in what position they may be placed. In frosty weather all pumps are liable to get damaged from the water freezing in the pipes, where the engine is exposed to the influence of the weather overnight. It is highly necessary under these circumstances to have a test plug tap fitted, to see if the pump is free before starting the engine; a cock and pipe should also be fitted to allow steam into the pump, to thaw the ice in cold climates; but probably if the water was allowed to flow out of the pump by the cock as already described, when the engine was in the shed at the workshops, there would be no danger from freezing. When the engine is running there is but little danger from frost, as the circulation of the water from the tender can always be more or less maintained. This motion of the water, partial as it may be, tends to the prevention of accident in all pipes which are liable to be damaged from the expansion of water when frozen. With inside-cylinder arrangement the pump ram is worked directly from a prolongation of the gudgeon of the crosshead; the pump being fitted to the main frame, the front end is fitted to the motion plate, and the back end is bolted to the frame, flanges being cast on the barrel of the pump for that purpose. These pumps consist of the working chamber, the plunger or ram, the valve chambers, the suction and delivery valve, and the non-return valve, fitted to the side of the boiler, while, in some instances, although by no means general, a plain plug tap has been fitted to the side of the boiler. We prefer the self-acting non-return valve, although a plug tap may be fitted between it and the boiler, to be shut off when the non-return valve or other pump valves require inspecting when the engine is under steam.

The pump barrel should be cast of tough brass, but in many instances toughened cast iron has been used. Muntz metal is now universally used for the plungers, which are connected to the crosshead of the engine by means of a wrought-iron eye, keyed to the plunger, a hole being bored out in the prolongation of the eye piece for receiving the part turned down on the end of the pump ram. The eye is simply held in position on the crosshead with a set screw, the point of the steel screw being indented into the gudgeon. When cast-iron barrels are adopted, the stuffing box for the plunger is fitted with a bottom ring and gland piece of brass; the latter should have an oil chamber cast along with it for lubricating the ram, fitted with a siphon wick.

In the arrangement having the barrel of brass, the valve chest is cast in one piece, containing the suction, discharge, and non-return valves, which are of the ball description, having cages for the guidance of the balls, which are cast along with the screwed caps on the discharge and non-return valve chests, let into the chest for the suction valve, and held in position with the flange on the suction pipe; all the various fittings are noted by letters on the engraving Fig. 523.

In the arrangement shown (Fig. 524) the valve boxes of brass are all separate for the suction, discharge, and non-return valves; but in

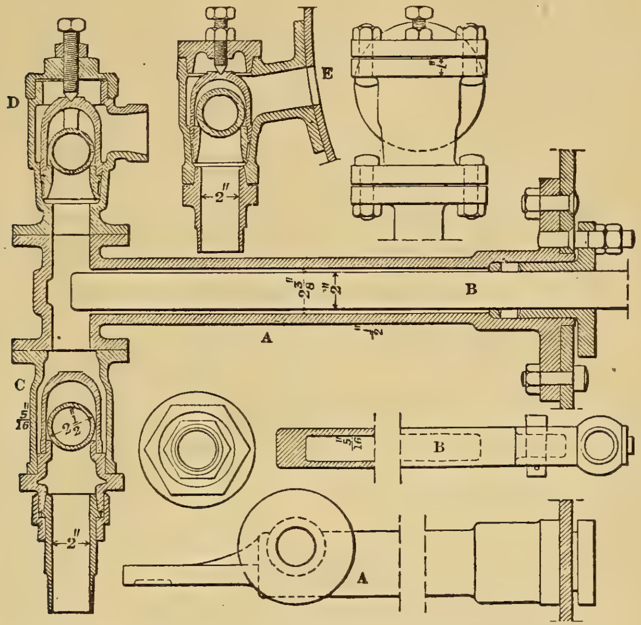
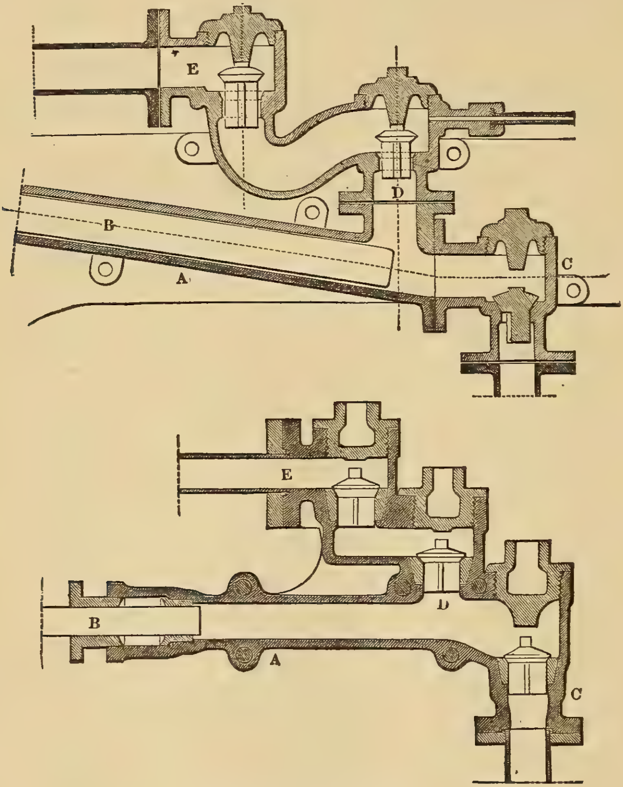


Fig. 524.—Feed Pump with Cast-iron Barrel and Valve Chests of Brass.

A, Pump barrel. B, Plunger and eye-piece. C, Suction valve box. D, Delivery valve box. E, Non-return valve box on boiler.

some cast iron is adopted for the suction and discharge boxes, and they are cast along with the pump barrel. The cages are held in position with a screw bolt and jam nut bearing on them, while the suction cage is held in position with a flange when the valve box is of brass, having a taper union piece and nut for the suction pipe. The non-return valve box has a flange which fits the curve of the body of the boiler; in modern practice this flange is quite flat, fitting against a plate with a raised part, which is faced, the plate being rivetted to the body of the boiler. The position of the non-return valve on the body of the boiler is of the highest importance, it should be placed as near the smoke-box end as convenient; the injected water should be thrown into the boiler at that part where the temperature of the surfaces exposed to the action of the flame and heated gases is the least. If the water is injected at the fire-box end, the tubes, being greatly heated, contract, and draw out of the holes in the tube plate, causing leakage; and, moreover, when cold water is injected into that part of a boiler where the steam is more readily produced, it must have a tendency to reduce the temperature of the steam, and consequently increase the consumption of fuel. Wherever the non-return valve is placed the pipe between it and the pump should be so constructed that it can yield with the expansion and contraction of the boiler, which can be easily done by giving the pipe a round bold radius where it bends up from the pump to the non-return valve box. Some form a U bend in the pipe. We prefer the bold radius given to the pipe, as the water flows through



Figs. 525, 526.—Feed Pumps.

A A, Pump barrels. B B, Plungers. C C, Suction valves. D D, Delivery valves. E E, Non-return valves.

it more freely. At the same time the pipe is not so much strained with the expansion and contraction of the boiler; and in fact this is the only part where the expansion affects the machinery, owing to the pump being attached to the frame, while the boiler is free to expand independently of the framing. All the flanges on the valve boxes should be of great thickness, more especially when of brass, as with frequent jointing and disjointing the flanges would be bent. And the bonnets or caps are liable to spring under the great pressure they are subjected to when going at high velocity, unless they are made very strong.

In other pump arrangements the valves have their webs with broad surfaces for guiding the valve in the seating, as in Figs. 525, 526, while others (Fig. 527) have guiding pieces with no webs, with stops so as to limit the lift. A pet plug tap (Fig. 528) is fitted between the discharge valve and the non-return valve; it is calculated to allow any air or steam collecting between the valves to escape, as also to test the action of the pump. This tap may be fitted directly to the valve box, with rod passing along to the platform; in other cases a pipe is fitted, having the tap close at hand near the platform. In all pumps it is found a great advantage to have the space between the ram and the body of the pump as little as possible, as a better vacuum is obtained in the first instance when no water is in the pump, or in technical language the pump *fangs* more readily.

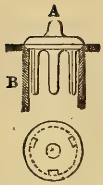


Fig. 527.—Feed-pump Valve.

A, Valve. B, Seat.

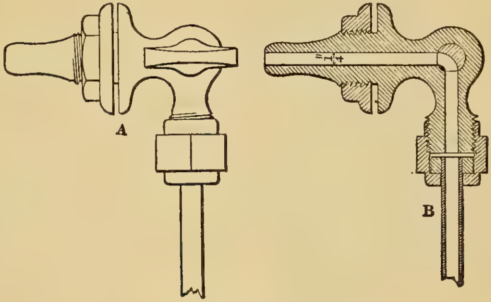


Fig. 528.—Pet Plug Tap.

A, Pet plug tap. B, Pipe.

There can be no doubt that the pressure at the commencement of the stroke is greatest on the ram, owing to the area of the valves being greater on the top surface, and that the valve closes with considerable shock. With a view, therefore, to soften the action of the valves, air vessels have been adopted on the suction and discharge boxes, with cup valves working in a cage, similar to the ball-valve arrangements, and it is found necessary to limit the lift of the valves, which varies from ⅜ to ¼ of an inch. A valve with a greater lift must necessarily return with much greater velocity, giving repeated blows, which soon injure the surfaces, but the blows can be greatly softened by the adoption of air chambers, forming elastic cushions that tend to relieve the pipes, while they also insure a steady flow both into and from the pump. The non-return valve (Fig. 530) on the cup principle is likewise adopted, the box being fitted with an expansion stuffing box and gland; by this means the feed pipe expands and contracts freely, thus forming a yielding medium between the pump and the boiler.

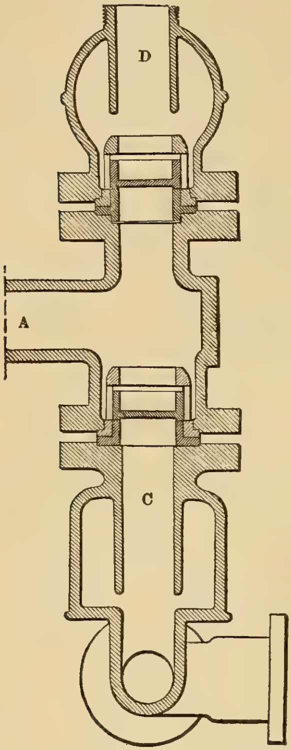


Fig. 529.—Air Chambers. Valves.

A, Pump barrel. C, Air vessel and suction valves, and D, Delivery valve and air vessel.

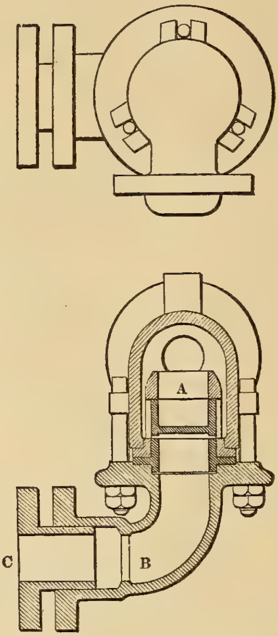


Fig. 530.—Non-return Valve and Box.

A, Non-return valve and box. B, Pipe from pump. C, Expansion joint.

Short-stroke pumps, having a hollow plunger, have been used, the plunger being actuated by an eccentric for that purpose; placing the rod on the back eccentric for the valve motion is a bad arrangement, that should never be attempted. The strain on these pumps is somewhat severe owing to their large area; consequently, when the eccentric for the valve has its own legitimate duty to do, and likewise to drive a pump plunger, the wear becomes very great, destroying in a measure the correct action of the main steam valves, so it becomes imperative to adopt an eccentric for driving the plunger alone.

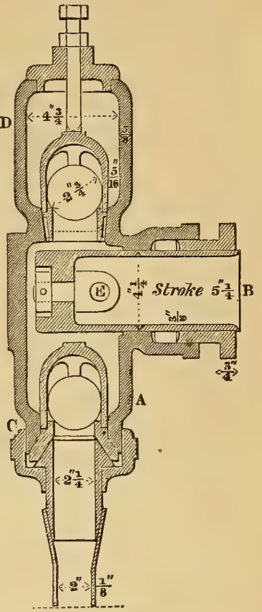


Fig. 531.—Short-stroke Feed Pump. A, Pump barrel. B, Plunger and stuffing box. C, Suction valve. D, Delivery valve. E, Stud for the eccentric rod.

Ball valves are sometimes adopted in these short-stroke pumps, similar in construction to those already described, and shown in detail. In other arrangements the valves are feathered, and are guided at the top with a short spindle working in a hole bored out in the cover for the valve chest; at the side of this guiding piece a very small hole is bored, through this the valve spindle ejects the water above it in a gradual manner, forming a water-cushion for the valve lifting against instead of striking against a stop, and which tends to soften

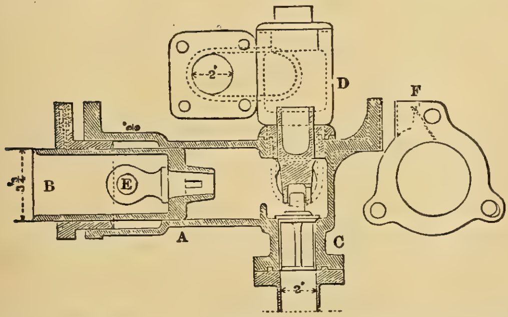


Fig. 532.—Feed Pump with Feather Valve having a Spindle on the Top.
A, Pump barrel. B, Plunger and stuffing box. C, Suction valve.
D, Delivery-valve box. E, Stud for the eccentric rod.
F, Oil cup.

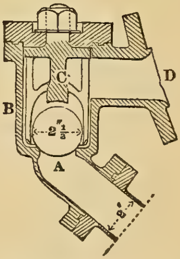


Fig. 533.—Non-return Valve.
A, Ball valve. B, Valve chest.
C, Cage. D, Flange for bolting to the boiler.

the action. The plunger of the pump has a stud secured to the plunger with a cotter, and in some a nut, while the eccentric and rod are of the ordinary description, with cast-iron sheave, brass straps, and wrought-iron connecting rod. The non-return valve connected with the latter arrangement is of the ball type, with cage secured to the cover by a single nut, while there is a stop cast along with the cage for regulating the lift of the ball. In another arrangement of short-stroke pump the jointed stud, placed inside of the ram is so situated that the thrust of the eccentric rod is taken on the gland and ring fitted to the bottom of the stuffing box directly; by this means the pump ram is not so liable to tilt. The gland for the stuffing box shows the arrangement of oil cup, which is cast along with it for lubricating the plunger.

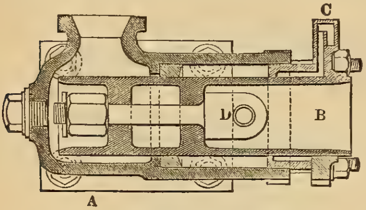
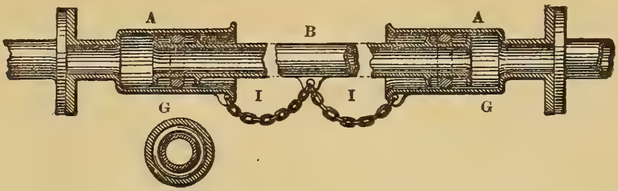


Fig. 534.—Feed Pump.

A, Pump barrel. B, Plungers and stuffing box. C, Oil cup. D, Stud for the eccentric rod.

In fixing these pumps it is preferable to keep them entirely clear of the boiler. They are generally fitted to a vertical plate, the pump is bolted on with the same flange as takes the gland bolts, the pump being short requiring no other support. In this arrangement the pump is placed in front of the driving wheels, while in others, when it is placed behind the driving wheels, a flange is cast on the bottom of the pump, which is bolted to a vertical plate placed at a short distance from the fire box, which is securely rivetted to the framing. With the view of giving greater strength to resist the thrust of the plunger, the plate for bolting the pump to has been placed on its side in the form of a beam, having flanges cast on the pump at the side for bolting thereto. All these different arrangements are preferable to fixing the pump to plate brackets attached to the fire box and shell of the boiler, as the strain is liable to affect the joints of the boiler, causing leakage.

Ball-and-socket joints with a sliding pipe were at one time much used for forming the connection between the pump and the tender, fitted with screw couplings for readily connecting and disconnecting the union between the tender and engine. A branch is made on the pipe for fitting the heating pipe, with plug tap on the boiler for allowing any surplus of steam to be blown into the tank for heating the water; the steam being let into the tank when the safety valves blow off, which mostly takes place when approaching stations; and great waste of steam would occur when the train is detained at the station were it not profitably utilized in heating the feed water.



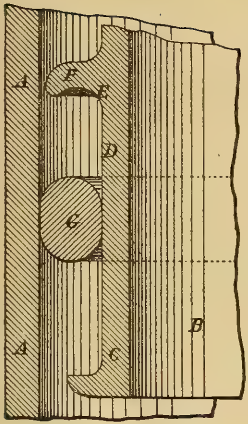


Fig. 535.—Union Pipe between Engine and Tender.

These ball-and-socket connections are very expensive in first cost, and prove a continual source of annoyance and expense in keeping such fine fittings in proper repair. A simpler connection is obtained by using a flexible hose, manufactured of canvas and india rubber, with a coiled wire inside which readily yields with the motion, and prevents the flexible hose from collapsing, the union being formed with a screwed coupling. The flexible hose, however, is also a source of trouble, as it soon deteriorates unless of very superior manufacture. To remedy the practical difficulties in both of these connections various plans have been tried: we notice one that has given a measure of success. The arrangement consists of two cylinders A A (Fig. 535), of brass or cast iron, one of which is bolted in the usual manner to the feed pipe of the engine, and the other to that of the tender; they are both bored out smooth and parallel; B is a connecting tube of brass or cast iron, having the ends turned, the part from C to D being parallel, and that from D to E coned; the collars, F, are curved as shown; G G are elastic rings of vulcanized india rubber, which, when at work, roll between the cylinders, A A, and the connecting tube, B; I I are light chains used for the purpose of keeping the tube, B, in its proper position; they are left slack to an extent of one half, the greatest amount of travel required between the engine and tender. The advantages which this arrangement appears to possess are its extreme simplicity, and consequently cheapness both in first cost and current repair, and the great durability of the only wearing parts, the motion of the elastic rings when at work being a rolling instead of a sliding action. Also the absolute tightness of the joints when the steam is blown from the boiler into the tender tank, as the elastic rings, G G, are then forced up the cone, D E, by the increased pressure, and are prevented from blowing out by the collars, F, which are curved as shown for the purpose of enabling the rings to adjust themselves readily to their proper position when the pressure is removed, which they do as soon as the engine is put in motion. The india-rubber rings, G, are made slightly larger than the space into which they fit, for the purpose of insuring a thoroughly water-tight joint; the cylinders, A, are $3\frac{1}{16}$ inches inside diameter, and the tube, B, 2 inches diameter outside; the ring is made $3\frac{1}{8}$ inches outside diameter and $1\frac{7}{8}$ inch inside diameter, the section of the ring being a circle $\frac{5}{8}$ inch diameter; of course these dimensions vary with the size of the pumps. Wrought-iron hanging brackets of plate iron or round forged bars are hung from the framing on the foot plate for supporting the ends of the pipes, placed close up to the screwed coupling; they are fitted with a cap in some, and a strap bolt in others, for readily connecting and disconnecting without distending the flanges on the pipe.

The *auxiliary engine* or *steam pump* (Fig. 536) is sometimes fitted to the locomotive as the only means of pumping the feed water into the boiler, such as on short mineral lines where there are frequent stoppages; in such cases the ordinary feed pumps have been entirely dispensed with. The steam pump is serviceable in all engines as a means of pumping in the water when the locomotive engine is at rest. The steam pump possesses the advantage of being allowed to work at a uniform speed, while the ordinary pumps have often to work unfavourably at a high velocity. The steam pump should be so constructed as to take up little room, consequently the best form of design is long and narrow; in the example given, the suction and delivery valve chambers are fitted with air vessels, which tend to soften the action of the valves, and equalize the flow into and out of the pump. The waste steam should be discharged into the tank on the tender, thus utilizing the exhaust steam in heating the feed water.

The *injector* is an instrument used for feeding the boiler, and certainly is a very ingenious contrivance; the engraving (Fig. 537) shows clearly how it is arranged. The central cone spindle is made adjustable so as to allow the exact quantity of steam to pass, while the outer cone pipe can also be adjusted for allowing the necessary quantity of water to pass around the annular space left between it and the outer casing. This instrument works best with cold water, and we are inclined to think that the water is simply injected into the boiler by the velocity it acquires from the atmospheric and steam pressure; in truth it works as a condenser. Were the water in the tank at the boiling point, and the steam turned on from the boiler, no water could be injected into the boiler from the tank; but the water, being comparatively cold, will flow in. Now we consider this is to be accounted for by the steam rushing against the cold water, forming a partial vacuum; the atmospheric pressure then comes to bear, and the water is simply injected into the boiler by the atmospheric and steam pressure. The valve shown on the underside is to prevent the water in the boiler flowing out when the apparatus is not working. A very large plug tap and pipe is fitted to the boiler in comparison to the small water nozzle, and in fact the pipe is much larger than what is fitted to an ordinary steam pump, thus giving a full command of steam for injecting the water rapidly into

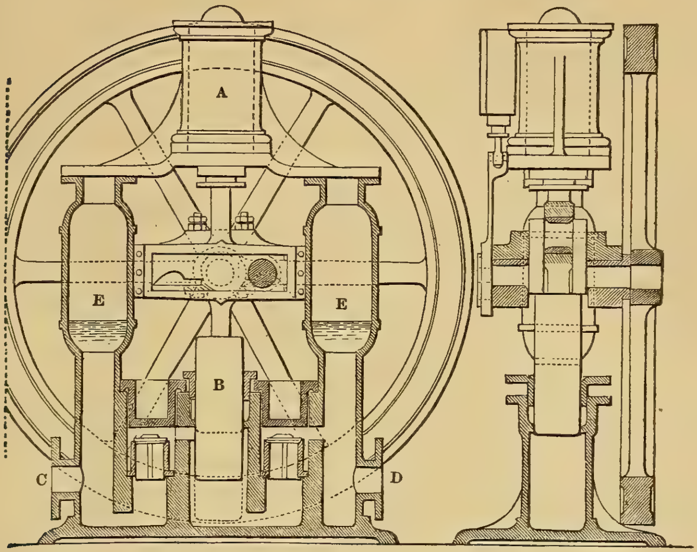


Fig. 536.—Auxiliary Feed Pump.

A, Steam cylinder. B, Pump plunger. C, Inlet passage. D, Outlet passage. E, E, Air vessels.

the boiler. The suction pipe should be properly guarded in the tank with a rose having very small holes, as the smallest hard substance would lodge in the nozzle, and completely destroy the action of the instrument. The only benefit in using the injector seems to be its economy as regards repairs, which in ordinary pumps are heavy. But we are of opinion that a steam pump or auxiliary engine on the double-acting principle is far more economical as regards the steam required to throw a given quantity of water into the boiler. The plug tap, as in fact all steam plug taps worked by hand, should be fitted with a wooden ferrule fixed in the handle; wood being a non-conductor, the handle always remains cool, but if of brass or other metal, it at times becomes too hot to grasp.

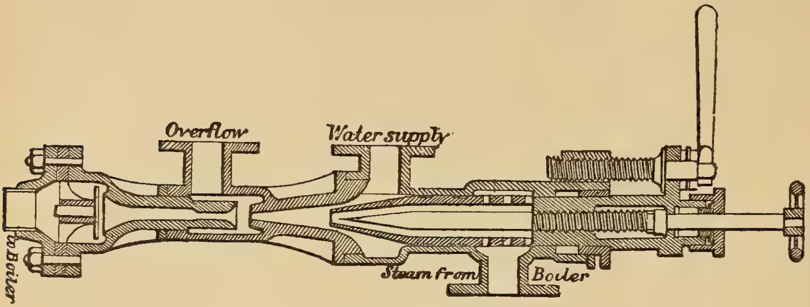


Fig. 537.—Injector.

Feed-water heaters appear to have been applied with success to locomotive engine boilers. The principle upon which these appliances depend is the delivery of the feed water to the boiler at a uniformly high temperature, such as 200° F. and higher, and the freeing of the water from impurities. Exhaust steam is used, and in some cases live steam from the boiler. The exhaust steam is passed into tubes surrounded by the feed water, contained in a strong casing, and after circulating, passes off. The water receives so much heat from the surfaces of the tubes, and is afterwards further heated by a coil of pipes containing live steam. Any matter precipitated as a deposit is received in a filter chamber containing charcoal, and the water thus purified and heated passes to the boiler.

When applied to locomotive engines two pipes connect the heater with the blast nozzle conveying the exhaust steam to and from the heater; the water from the condensed steam being suitably drawn off. This amount appears to be twenty per cent. of the whole used.

THE AMERICAN LOCOMOTIVE.

Details of boiler, fire box, tubes, &c.—The fire boxes of American locomotive engines are made large as wood fuel is greatly used in these engines; they are of the usual form, strongly stayed at the top with beam stays, which run longitudinally, and in some transversely, care being taken that the ends of the bars rest on the upper edge of the end or side plates. In addition to these bars the top of the fire box is stayed with vertical rods secured to the bars and rivetted to the top of the outside shell. The sides of the fire box have screwed stays, which are screwed through the inside and outside shells, and then rivetted over at the ends. Although these stays have been originally made of the best iron, they soon become crystalline in texture, and rapid corrosion also sets in; the former of these effects is attributed to the expansion and contraction of the plates, causing a bending and unbending strain, more especially at the top rows, where the expansion of the plates is the greatest. Were the inside and outside fire boxes expanding equally, there would be no cross strain on these stays; but the inside fire box must expand more than the outside shell, consequently the stays must bend and unbend, the bending taking

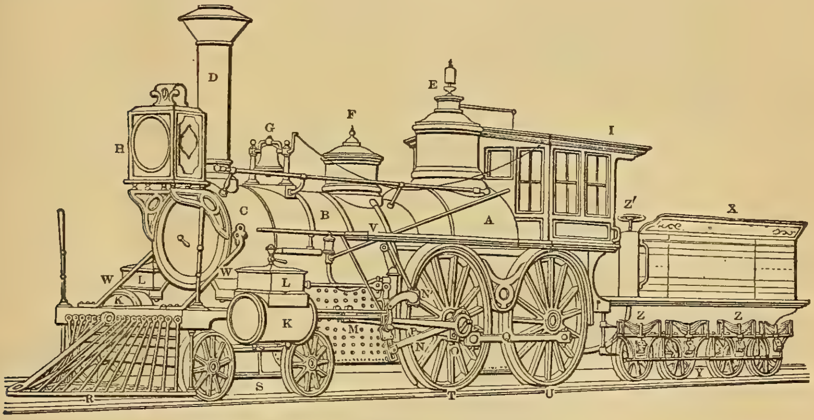


Fig. 538.—General Arrangement of Coal-burning Engines.

A, Fire box. B, Body of boiler. C, Smoke box. D, Chimney. E, Steam dome. F, Sand box. G, Bell. H, Lamp. I, Cab. K K, Cylinders. L L, Valve casings. M, Guide bars. N, Eccentric and link motion. N', Weigh shaft. O, Crank pin. P, Connecting rod. Q, Side rod. R, Cow-catcher. S, Bogie wheels. T, Driving wheel. U, Trailing wheel. V, Platform. W W, Stays. X, Tender. Y, Tender wheels. Z, Springs. Z', Brake handle.

place when the fire box is thoroughly heated, and *vice versa.* The stays in some instances have been turned down at the middle of their length, thus securing some lateral strain without permanent injury.

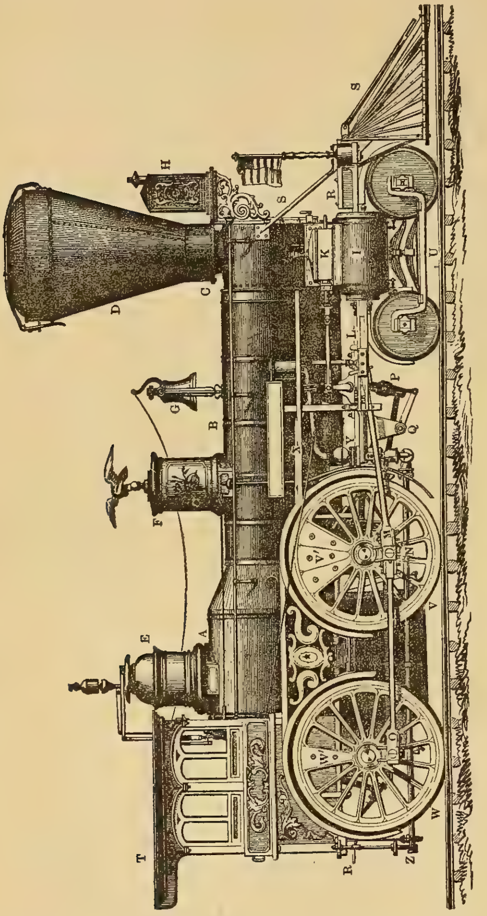
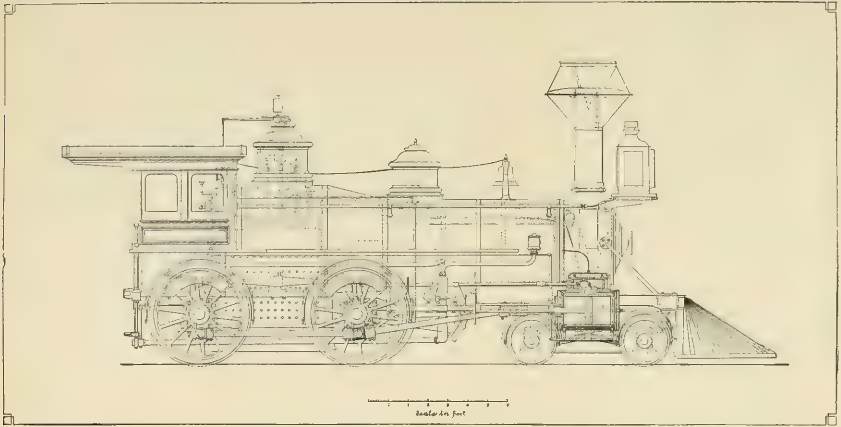


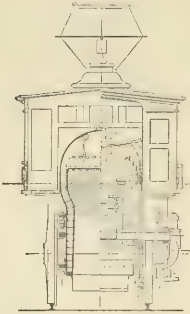
Fig. 538A.—Standard American Woodburning Locomotiv

A, Fire box. B, Body of boiler. C, Smoke box. D, Chimney and spark arrester. E, Steam dome, safety valves, and whistle. F, Sand box. G, Bell. H, Lamp. I, Cylinder. K, Valve casing. L, Motion bars. M, Connecting rod. N, Crank pin. O, Side rod. P, Eccentrics and link motion. Q, Weigh shaft. R R, Main framing. S, Cowcatcher and stays. T, Cab. U, Bogie. V, Driving wheel. V′, Balance weight. W, Trailing wheel. W′, Balance weight. X, Platform. Y, Pump and air vessels. &c. Z, Pipe for the tender

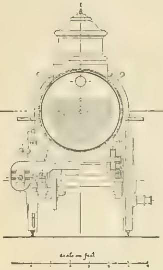
The plates of the fire box are flanged as in British practice with a separate crown plate, which is at times flanged downwards on two sides, while in others the side plates are bent, and are of sufficient length to form the crown, the seam of rivets being in the centre of the fire box. The junction between the inside and outside shells at the bottom is made with a solid hoop fitted and rivetted between the two shells. The fire boxes for wood burning are of iron plates; the sides are ¼ inch thick, which has been found less liable to



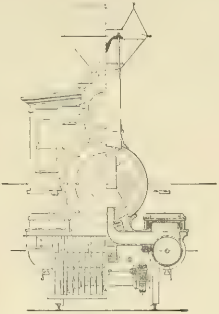
AMERICAN PASSENGER FAST LOCOMOTIVE. (SIDE ELEVATION AND SECTION.)
By the Baldwin Locomotive Works, Philadelphia, Pa., for the Northern Pacific R. R., 1882.



AMERICAN PASSENGER LOCOMOTIVE.
Half Elevation at Back, and Half Section through Fire-Box.



AMERICAN PASSENGER LOCOMOTIVE
Half Sections at Guide Yoke, and Reverse Shaft.



AMERICAN PASSENGER LOCOMOTIVE.
Half Elevation at Front, and Half Section through Smoke Arch and Cylinders.

(BALDWIN LOCOMOTIVE WORKS, 1882.)

blister than thicker plates; the tube plates $\frac{5}{16}$ to $\frac{3}{8}$ inch in thickness, and the crown $\frac{5}{16}$ inch thick, Lowmoor or Bowling iron being preferred, both as regards soundness and facility for flanging, although American iron is allowed to be stronger.

The water spaces around the fire box, when wood is used as fuel, are narrow, varying from 1 ¼ inch to 2 inches, while for coal burning 3 inches clear space is allowed. For promoting a free circulation of the water a thin plate is placed in the middle of the water space, parallel with the sides of the fire box; by this means an ascending and descending current is maintained, the ascending current flowing from the bottom between the partition and the sides of the inside shell, while the descending current takes place between the partition and the outside shell. In some fire boxes suited for coal burning circulating pipes have been fitted, connecting the underside of the barrel with the bottom of the water space, which tends to effect a better circulation of the water; however, the best plan for doing so is by making the water spaces of sufficient width tapering from the bottom upwards.

The top of the outside fire box in some examples projects above the barrel of the boiler from 9 to 12 inches, thus affording additional steam space and facility for inspection. It is connected with a sloping plate to the cylindrical part of the boiler; in the latter the plating is what is termed telescopic, arranged in rings which are largest at the fire-box end. The top of the outside shell in other examples is on a level line with the body of the boiler, and in both instances steam domes are fitted, placed on the top of the fire box in some, and body of the boiler in others. In cases where a large dome of say 36 inches in diameter is fitted to the barrel of the boiler, the hole cut in the plates is only 18 inches in diameter; this size is ample for inspection through the dome, and the barrel is not weakened so much. The smoke box is a continuation of the barrel, and as the cylinders are fastened thereto the plates forming it are of greater thickness than the body. Careful experiments on the strength of American boiler plates gives the following results:—

Process of Manufacture.	Rough-edge Bar.	Edge Filed Uniformly.	Notches Filed in the Bar on each Edge.
Piled iron,	23·7 tons.	25· tons.	28·24 tons.
Hammered iron,	21·2 ,,	24·81 ,,	26·1 ,,
Puddled iron,	23·37 ,,	22·8 ,,	27·87 ,,

with a reduction of say from 10 to 15 per cent. Formerly the body of the boiler was formed of plates ⅜ of an inch in thickness, with barrels from 36 to 40 inches in diameter, for 80 to 100 lb. steam pressure; this thickness has been reduced to ¼ inch, and in some $\frac{5}{16}$ of an inch, in thickness for barrels 43 to 50 inches in diameter, carrying 120 to 130 steam lb. pressure, while the plates of the smoke box may be taken at ⅜ of an inch in thickness as well as the tube plate in the smoke box. There is no angle iron used in the construction of the boiler, all the plates being flanged at the corners with a bold radius, single rivetting being adopted throughout the entire boiler.

The tubes used for wood burning are made of copper, brass, and sometimes of iron; with the former they are from No. 13 to No. 16 gauge, and are expanded in the holes with a tool for the purpose; no caulking should be adopted, as the tube plates are much thinner than in British practice, consequently not well calculated to bear the strain in the process of caulking without injury both to the plates and the tube, whose ends become brittle; in fact all boiler tubes are now expanded in the holes with an expanding mandrill for the purpose; ferrules are only used in the fire-box end; they are made of wrought iron, and in some instances cast iron is used, the latter permanently expanding with the heat, keeps the tubes tighter; however, they require to be made thicker than the wrought-iron ferrules, consequently the draught is partially impeded. The tubes vary from 1¾ inch to 2 inches in diameter, the latter being preferred, with ⅝ of an inch distance between them; it is generally allowed that tubes 2 inches in diameter make a better steam-producing boiler than tubes 1¾ inch in diameter, the same heating surface being presented in both cases. The tubes are preferred in vertical rows to insure free circulation of the water, as well as allowing the steam to rise freely.

The coals used in American engines are of the anthracite, bituminous, and semi-bituminous kinds. The former contains but little hydrogen, and is smokeless; bituminous coal produces much smoke, and both kinds form clinker. The semi-bituminous coal is not unlike Welsh coal. All the fire bars for coal burning should be made so as to clear the clinker; with that object in view they are fitted with a rocking apparatus that can be agitated when the engine is running, thus loosening the vitrified clinker.

The problem of coal burning without smoke, as in British practice, may effectually be carried out by using the best kind of coal, with frequent firing, and by making proper arrangements in the furnace for effectually mixing and igniting the gases and air, and keeping the grate free from clinker.

The induction by steam of currents of air, as in British practice, has proved the best and simplest mode of mixing the gases and air, and will no doubt be found advantageous for American coal-burning locomotive engines.

The smoke box, as before stated, is a continuation of the boiler, the tube plate is flanged, and the smoke-box plates rivetted thereto, while at the door end a wrought-iron hoop is worked inside and rivetted to the plates, while some have a hoop at the back end, placed between the shell plates of the boiler and that of the smoke box, thus greatly stiffening the smoke box for bolting the cylinders thereto. The smoke-box door is generally circular, hinged and fastened in a similar way to that in British practice, while some have a segment of the circle cut away, which is hinged vertically and fastened at the bottom.

The chimney of the American locomotive is a very plain affair; but the spark arrester attached to it is peculiar. No arrangement seems to work better than the conical deflector placed a few inches above the ordinary chimney, which throws down the sparks into the receiver surrounding the chimney, and from its large diameter forms a characteristic feature of the American locomotive, presenting the appearance of a huge inverted cone, the top being covered with a fine wire-gauze protection to retain the finer particles, as well as to allow the smoke and steam to escape (see Fig. 538A, p. 664). At the bottom of the receiver a door is fitted for the purpose of raking out the accumulation of charred wood; and in some a cast-iron socket is fitted to the top of the smoke box for receiving the small end of the receiver. The wire-gauze covering can likewise be readily removed, and is held down with a jointed strap with rod and catch. In other forms of spark arresters a series of curved vertical vanes are placed beneath the conical baffle plate; by this means the sparks receive a spiral motion, which tends to throw them against the sides of the receiver, and by their own weight they fall to the bottom, the smoke and steam passing through a series of wire-gauze rings placed at the top of the chimney. This form retained a greater portion of the sparks, and was mainly introduced on those railways where the sparks are so dangerous to trains freighted with cotton; however, the plan is more complicated, and as wire gauze has a tendency to impede the draught we certainly approve more of the former arrangement, which no doubt will continue in use until coal finally supersedes wood as fuel.

The ash pan is similar in construction to those already described, and is sometimes fitted with a door or damper at the front, while others have one at the front and back, which can be opened at pleasure from the foot plate by means of a jointed rod and handle, with notches for keeping the damper open at any required position.

The fire bars are of cast iron; in some cases cast in pairs, having a means of rocking them to loosen the clinker; in others four or more bars are cast in one piece, the bars resting on flat pieces of iron fastened at the front and back end of the fire box.

The variable blast nozzle is used in mostly all coal-burning locomotives; it is placed in some low down in the smoke box, nearly on a level with the bottom row of tubes, while in others the blast orifice is on a level with the top row of tubes.

The separate steam jet is likewise fitted to the chimney so as to increase the draught while the engine is standing, and is used to keep down the smoke at the stations by gently urging the fire, while the steam, mixing with the smoke, makes the latter not so black in appearance as it would otherwise be. Thus the smoke is partly consumed in the first instance by a rush of air through the grate, urged by this separate blast pipe with steam taken directly from the boiler, which, mixing with the smoke issuing from the chimney, renders it less opaque, and being forcibly ejected into the atmosphere, tends to scatter the volume that would otherwise issue slowly and densely from the chimney were not this appliance adopted.

Various contrivances have been adopted in order to equalize the draught through the tubes, more especially for coal-burning engines. In all tubular and other boilers, the heat naturally rises to the highest parts, consequently takes the shortest course through the upper row of tubes. To effect a better distribution the exhaust nozzle has been placed on a level with the bottom row of tubes; a pipe of about 10 inches was placed over the nozzle, extending a few inches within the base of the chimney, leaving an annular space of about 2½ inches in width all round the chimney; by this means the draught was urged through the openings at the top and bottom, and consequently more equally through the tubes. While in wood-burning engines a set of short pipes has been arranged one over another in the form of a truncated cone, leaving annular openings, through which the gases pass, the exhaust steam being discharged from the lower part of the cone.

To prevent radiation, the boiler is covered over with pine wood, termed cleading, over which is placed a covering of planished Russian sheet iron, having brass bands highly polished where the plates meet these bands; they are sometimes beaded or moulded, American engineers priding themselves on the high finish they give their engines.

The steam pipe, placed inside of the boiler, is sometimes perforated as in British practice, the openings in some being a triple row of slots, each 3½ inches long and ¼ and ⅜ wide at the firebox and smoke-box ends respectively. With this arrangement the regulator is placed in the smoke box, and can be more easily inspected than when inside of the boiler. In other arrangements the regulating valve is placed in the steam dome, an elbow branch piece being bolted to the side of the dome, taking the steam pipe passing along to the branch piece of the front tube plate; the steam pipe in such instances must be made of sufficient strength to prevent collapse.

Two safety valves are generally fitted, placed on the top of the steam dome; while in others a separate casting is used; this is preferable, as with the former arrangement there is a greater tendency to priming when the steam is blowing off; lever and spring balances are generally used, as in British practice, for resisting the steam pressure on the valve, and they are arranged so as to be reached by hand, as all safety valves should be; but unless experienced and careful men are employed as drivers and firemen safety valves of the lever kind may be tampered with in whatever position they may be placed on the boiler. The safety valves are generally fitted at the top of the safety-valve chest, while others are arranged on the cast-iron cover, forming the top of the steam chest, and are carried sufficiently high overhead, thus dispensing with steam funnels for carrying off the steam. The covering for the steam dome is of polished brass very elaborate in design; in some there is merely a bottom piece, with a recess at top of moulding for letting in the wood lagging, and which is secured at the top with a strap, the whole being covered with Russian iron highly planished.

Glass water gauges are not generally adopted in American locomotive engines; sometimes gauges on the float principle are used for indicating the height of water in the boiler, while others have merely test taps, arranged one above another. From three to seven of these taps are fitted, and an experienced man can tell, on one of them being opened, whether steam is blowing off, or steam and water combined, in which case it is seen that the water in the boiler is so far above the crown of the fire box. When steam alone is found blowing off, the next tap lower down is tried, and so on until the limit is indicated below which it is not safe to work the boiler. The pressure gauge is similar in construction to that adopted in British engines, Bourdon's being generally preferred; for a description see p. 575.

The steam whistle is larger than is used in British practice, the bell being 4½ inches diameter and 6 inches deep; instead of a plug tap, a conical valve admits the steam into the annular chamber, it is fitted with a spring, and when the whistle is placed on the top of the steam chest, on the body of the boiler, or on the top of fire box, it is fitted with a lever and rod passing along to the platform. The whistle produces a sound deep and powerful, and is chiefly used when the train is departing from and entering stations, as likewise signalling to the guard to turn on the break in cases of danger. A mechanical means of sounding the whistle on approaching level crossings has been carried out with a measure of success, consisting of a worm wheel placed on any of the engine-truck axles working a train of wheels which turns a drum, having catches for lifting the valve lever on the whistle, the catches being adjusted to the distance travelled over by the truck wheels of the engine. It is obvious that this plan would work well on certain lines, provided no slip occurred, and the truck wheels of the engine did not wear on the tyres, increasing the number of revolutions for a given distance travelled over; but as the wear must be very gradual, a provision for adjusting the mechanism is all that is required on the part of the engineman.

A large bell weighing upwards of 200 lbs. is fitted to a stand placed on the top and front of the body of the boiler, having a rope passing along to the platform, which is sounded on approaching and passing level crossings.

The head light is placed in a large lantern, fitted with brackets, secured to the front of the smoke box, and is fitted with a parabolic reflector plated with silver, the diameter varying from 18 inches to 22 inches, and about 16 inches in depth, concentrating and throwing the rays of light directly along the line, enabling the engineman on a dark night to distinguish objects for a considerable distance. Oil, and in some instances gas distilled from "burning fluid" is used in the lamps, the latter improving the brilliancy of the light.

A sand box is fitted to the top of the body of the boiler, with pipes passing down in front of the driving wheels, and is fitted with valves, levers, and rods, passing along to the platform; by this means the rails can be sanded simultaneously. These boxes are elaborate in design, and in some instances support the bracket for the great bell, by this means lessening the number of fixtures attached to the body of the boiler.

The blow-off plug valves, heating and lubricating taps, are similar in construction to those in British practice.

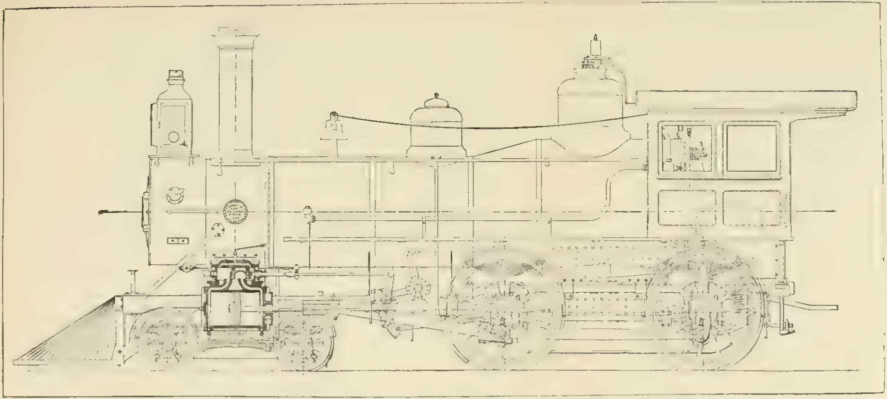
The hand rail is placed somewhat higher up than in British engines, and passes along from the front of the cab, and across at the front of the smoke box, the long studs or pillars for supporting it being secured to the body of the boiler and to the smoke box.

Cylinder and slide valve.—The cylinders are generally arranged outside of the framing, lying horizontally in some and diagonally in others, the inclination varying to suit the requirements. The cylinders are of cast iron, and great attention is paid to secure the best quality of material. They are cast open at both ends, the bearing surface of the covers being outside of the internal diameter, flanges being cast on for securing the covers thereto. The steam chest is jointed to the cylinder, not cast along with it as in British practice, thus simplifying the casting, the joint being metal to metal, carefully faced and scraped, and secured with bolts or studs in the usual manner. A port is cast on the cylinder for the admission of the steam from the boiler, which enters the valve casing through a rectangular port. The fastening of the cylinders to the smoke box is effectually carried out by means of brackets cast along with the cylinder, which have flanges for bolting to the top of the framing, and to the underside of the round smoke box, while some have the cylinders cast together.

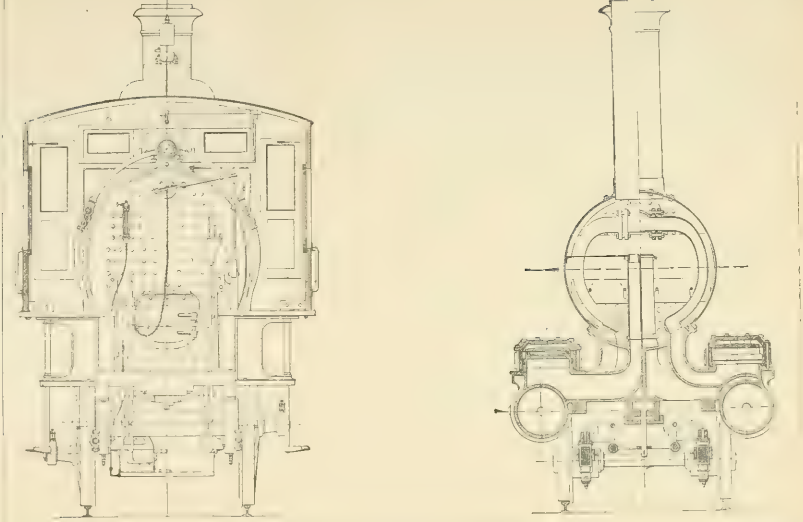
In other examples a separate casting, termed a saddle, is placed between the framing of the engine, and is curved to the round of the smoke box, to which it is bolted, as likewise a flange rests on each frame, both surfaces being accurately planed and strongly secured together; a flange, turned downwards, takes the inside of each frame, the whole making an extremely strong fastening between the framing and the smoke box. The exhaust passage for the waste steam is cast along with the saddle piece, whilst the steam passage is let into the side of the steam chest. The cylinder in this arrangement has a flange which rests on the top of the saddle, and another, which abuts on the outside of the frame, to which they are securely bolted.

In other arrangements the saddle is an open-ribbed casting, with a flange curved to the round of the smoke box, the saddle being the entire breadth between the frames, to which it is secured at the inside and bottom, with suitable flanges cast thereon through which the bolts pass; on the top side of the saddle vertical flanges are formed in the casting to which the cylinders are bolted, the waste steam pipe in such arrangements being cast along with the cylinder. Provision is made in the saddle for carrying the pin or surface plate on which the truck or bogie is centered. The steam ports are located on the top side of the cylinder, placed nearly centrally with the line of the main connecting rod; a plain valve of cast iron is used, this has been found to work very well when the cylinder face is of hard iron; it is, however, found that these faces work unevenly if not properly arranged, owing to the varying travel given by the link motion when cutting off at different grades of expansion. A steel plate has in some examples been screwed to the cylinder face, having the ports cut therein; the valve is made of hard brass, all the surfaces being properly planed and scraped. When separate expansion valves are used they are placed on the back of the main steam valve directly, or work on a plate having ports to suit, this plate forming a division across the steam chest. There can be no doubt that when the expansion valve is placed directly on the back of the main valve the cut off or suppression of the steam is more perfect, simply owing to less steam being admitted into the cylinder; whereas, when the expansion valve works on a plate forming a division in the steam chest, the steam chest proper must in each instance be filled with steam, consequently waste must occur. It must be borne in mind, however, that with the expansion valve on the back of the steam valve the surfaces work unevenly, and this is a drawback to their general adoption. Besides there can be no doubt that with a proper link motion a plain valve is best suited to work the steam expansively. The reduction of the working parts in the locomotive engine should be a main object, but expansive valve gear in many instances is very complicated, while the advantage is doubtful, and the repairs in some arrangements are heavy.

The steam chest, as before stated, is a separate casting, bolted to



PASSENGER LOCOMOTIVE, BUILT BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, 1888.



AMERICAN PASSENGER LOCOMOTIVE BUILT BY THE BALDWIN LOCOMOTIVE WORKS, PHILADELPHIA, 1888

Half Elevation at Back

Half Elevation at Front

the flange on the cylinder with stud bolts, and having a round collar bearing in a recess cut out in the top side of the valve casing, the bolts projecting beyond for taking the casing cover, having nuts and washers for securing the cover; the bolts are placed about 4½ inches from centre to centre, and pass down through shields cast in the valve casing. Were not such a precaution adopted, the bolts would rapidly corrode when in contact with the steam and steam currents continually passing through the casing. The cylinders and steam chests are properly clad and covered over with Russian sheet iron, and in some instances sheet brass highly polished, and which may easily be kept so. The valve rod passes through the back of the steam chest, having a suitable gland and stuffing box, with proper means for lubricating the rod; the mode of attachment to the valve is by means of a loose strap encircling it, thus the valve accommodates itself to the wear; in some cases the rod passes through the valve, and is prolonged at the back, working in a tube piece bolted to the valve casing; the valve is adjusted by nuts, a thread being cut on the rod.

The valve is lubricated by means of an oil or grease cup placed on the top of the valve-casing cover, the lubricant finding its way into the cylinder, keeping the rubbing surface thoroughly lubricated. Plug taps are fitted to the underside of the cylinder, one at each end for ejecting the water collecting from condensation and priming.

Valve motion.—To recapitulate all the various arrangements of valve motion that have been used is needless, as the double eccentrics and single link for working the steam expansively are now fully recognized by American engineers. The position of the steam valve being generally on the top side of the cylinder, the motion is more indirect than that usually adopted in British practice.

The shifting link is commonly used over that of the stationary link, and the motion of it given by the double eccentrics is communicated to the valve by levers fixed on a short rocking shaft placed on each side of the framing. The maximum admission of the steam into the cylinder is about 90 per cent. of the stroke of the piston, while the minimum admission is about 35 per cent. of the stroke of the piston; the valve having a throw of from 4⅝ inches to 5 inches, the outside lap being from ⅝ of an inch to 1 inch at each end, while the inside lap is nil; or, in other words, the edge of the valve is in line with the inside of the port. Some even consider it advisable to give a little clearance.

Cast-iron eccentric straps are very generally used; they are found to wear better than brass straps when the friction is not very severe. The rods are of wrought iron, connected to the strap with side bolts, a broad palm being forged on the rods, having a corresponding piece cast along with the front half of the eccentric strap. The rods are attached to the link with a plain eye having a pin of steel, and sometimes a bush of steel is placed in the link. The link is usually of the solid description, formed of wrought iron, case hardened. The snugs for taking the eccentric rods are at the back of the link, and very rarely at the ends. In some examples the link is of cast iron, and although the weight is considerable they are found to work and wear satisfactorily.

The point of suspension is various, and is generally determined by trial, which can readily be done with a full sized model; in some the point of suspension is exactly in the centre of the link, both vertically and horizontally, while in others it is a few inches above, or an inch or so in front or behind the centre of the link. The radius of the link, we consider, should in all cases be the exact distance between the centre of the link when placed vertically at half stroke of steam valve and the centre of the eccentric. The weigh shaft or reversing shaft, on which levers are placed in connection with the lifting rod on the link, is very similar to those used in British engines; the brackets for supporting it being bolted to the top of the frame, one on each side. There are two lifting arms keyed on, and one reversing arm, as likewise a weighted arm for balancing the weight of the links, rods, &c.; in some instances a spiral spring is used for this purpose, which can be placed on the weigh shaft or at the foot plate according to the arrangement.

The reversing rod attached to the arm on the weigh shaft passes along to the reversing lever and quadrant placed on the foot plate, the quadrant being cut with suitable notches for taking the catch on the reversing lever. When a spring is used at the platform for balancing or easing the weight of the links, &c., in reversing the motion, a coiled spring is placed inside of a hollow sheave or drum which revolves on a central pin, the spring being held with a fixed point at the spindle, and the other end secured to the drum; a band connects the drum with the short arm of the reversing lever, so that when the links are lowered the spring stores up force to ease the labour of lifting them. As the trains in mostly all double-lined railways run up on the right-hand line, the levers, and consequently the position of the engine driver, being on the outside of the double line is generally on the right hand, while on some railways *vice versa*, or, in other words, the engineman's position should always be on the side of the engine next the platform of the railway stations, in order that he may see distinctly the signals given by the guard or conductor of the train.

Piston.—The piston commonly used in American practice is of cast iron in the body, with a junk ring of the same material secured to the body by four or more bolts; the packing rings, two in number, are made of a composition of 9 of copper and 1 of tin; they are cut at one part, and the rings are lined or plugged with Babbitt metal. A ring of wrought iron or cast iron, ½ inch in thickness, is put inside of the brass rings, and between it and the body of the piston small springs are placed with set screws for adjusting the outward pressure against the surface of the cylinder. The inside ring likewise tends to prevent the steam passing into the body of the piston. Cast-iron packing rings, even when lined with Babbitt metal, have invariably been found to rut the surface of the cylinder. Sometimes the packing rings are expanded with a single wedge as in British practice, while self-expanding packing rings do not seem to find much favour with American engineers. Wrought-iron pistons have in a few instances been adopted with advantage, as there can be no doubt that these pistons are light compared with the cast-iron form, tending to reduce the weight of the reciprocating parts, and consequently making the repairs less, when the permanent weight is heavy; with the rapid reciprocation as in the locomotive engine, the strain on the moving parts is very severe. In these examples the piston is forged along with the rod, while for the cast-iron pistons a simple key secures it to the rod, which is made conical, and properly ground into the conical hole bored out in the boss.

Piston rod, crosshead, and motion bars.—The end of the piston rod is made conical, fitting exactly the hole bored out in the boss and ground together with it, making the union perfectly steam tight, the piston rod being secured to the piston and crosshead with single split cotters. The gland on the back of the cylinder for the piston rod is packed with hemp, and in some metallic packing is used. In the bottom of the stuffing box an annular metallic ring is placed, surrounding but not nearly touching the rod; it is of a conical form with the larger opening at its outer end. Composition rings, cut at one part and bored out to fit tightly against the piston rod, are placed inside of the conical metallic ring already described, the outer diameter of the rings being turned conically. The gland is screwed up pressing these rings closely against the piston rod, and as the outer ring does not fill exactly the stuffing box, and the gland is bored out somewhat larger than the rod, the packing rings can thus accommodate themselves should the piston rod from wear be not in the same centre line as the cylinder. The composition used for the packing rings is 9 of tin and 1 of copper. Of course the piston rod in the first instance must be quite smooth and perfectly parallel. The crosshead in a number of examples is of cast iron, with the pin for taking the connecting rod cast on, and which is turned with a tool for the purpose. The sliding block and crosshead are cast all in one piece, and a snug is also cast on for taking the pump ram. Wrought-iron crossheads are likewise used, and certainly we prefer this thoroughly British mode, as they are much lighter, reducing the weight of the permanent moving parts to the minimum. The motion bars are of iron, of the double form, placed on each side of the piston rod. When cast-iron crossheads are used case hardening is not required, but when the sliding blocks are of brass or composition metal the bars are case hardened, or steel used in their construction. The width of each motion bar varies from 3 to 4 inches, while the length of the sliding block is about 16 inches. The motion bars are secured to lugs cast on the cylinder cover at the one end and to a bracket through which the connecting rod works at the back end, the bracket being secured to the framing and boiler. When no lining pieces with means of adjustment are fitted to the crosshead thin slips of metal are placed between the lugs on the cover and bracket, which are removed, or as in British practice filed down to suit the wear of the crosshead. A lubricating cup is placed on the top motion bars for supplying the rubbing surfaces with oil or other lubricant.

Connecting rod.—The connecting rod is formed, as in British practice, flat on the sides, the middle part of the rod is rounded at the top and bottom, with butts at ends for receiving the straps and brasses; sometimes the middle part of the rod at sides has a semicircular groove planed out, thus reducing the weight, while the section is very stiff. The brasses have all square ends, excepting the outer half of the small end for the crosshead of the piston rod, which is made curved, the flanges projecting on each side and made the full width of the strap. The brasses, with flat ends and flanges so arranged, wear much longer than those with the ends circular and the flanges narrow, being held much more steadily in position. The straps are secured by two bolts, with nuts and jam nuts; the cotter for tightening up the brasses bears on an iron plate let into the brass, thus preventing the thin cotter from cutting the brass, in which way it would soon become loose were not the plate interposed between the brass and the cotter. A set screw bears on the side of the cotter, a hole being tapped on the side of the butt; by this means the cotter is held firmly in the slot. An oil cup is placed on the top side of the strap, provided with a siphon wick.

The rods for coupling the wheels together are arranged in a similar way with straps, keys, and brasses; the brasses are made to form a close cap on the outside, by this means excluding dust and grit; there are two bolts and nuts passing through the straps and butts at each end, with a single cotter at the one end placed inside, and at the other end a cotter both in the inside and outside ends of the brasses; by this means the centres of the bushes can always be adjusted to the exact distance between the centres of the wheels. In order to reduce the overhang of the pins for taking the outside rod, various arrangements have been tried to couple the wheels in the same line as that of the main connecting rod. One of these arrangements has a pin formed on the end of the strap for the main connecting rod, taking the outside rod; but it is obvious that this plan is highly objectionable, as by the oscillation of the connecting rod, the distance between the crank pins of the two pairs of wheels is alternately lengthened and shortened, imposing a severe strain on the crank pins. Another plan has the strap on the forward end of the coupling rod prolonged and fitted with brasses for taking the forked end of the main connecting rod; by this means the rod is coupled a few inches in advance of the crank pin, and although by this arrangement an indirect strain is imposed on the bolts, yet the plan worked much better than the former one. A third arrangement consists in making the forward pin longer than usual, and the brasses circular at the middle and square at the ends. The main rod is forked and provided with straps for taking the square ends of the brasses, and fitted with bolts and keys. The coupling rod is fitted with a strap, with bolts and keys, and is coupled and worked between the forks on the main connecting rod, the middle part of the main connecting rod brass being turned for its reception. This form of direct connection recommends itself as being correct in principle, and may be otherwise arranged in detail to suit the views of the designer.

Wheels and axles, and crank pins.—Although cast-iron wheels are much more liable to fracture, more especially in cold weather, they are extensively used in American engines; but there can be no doubt that wrought-iron wheels are preferable, their weight being less, and having greater elasticity with less liability to fracture. The driving wheels for goods engines, ranging from about 3½ feet to 4½ feet in diameter, are made of the plate or disc form, similar to those used for the bogie or forward-truck wheels. Driving wheels 5 feet 6 inches or so in diameter have from fourteen to sixteen arms cast along with the nave and inside tyre. As these wheels are heavy, and the permanent way rather rough and rigid, more especially in the winter months, the outside tyres are of great strength, varying from 2¼ inches to 3½ inches in thickness according to the requirements, the latter thickness being used with engines having 5 tons on a wheel; and even when those tyres wear down to about 2 inches they stretch, become loose, and require to be renewed.

Sometimes the front pair of coupled wheels, where of course a bogie is placed in front of the engine, have no flanges; this is to facilitate the engine turning curves; but in recent practice flanges are put on all the wheels, while the engines turn as before curves from 600 to 1000 feet radius, and run more steadily, and the diameter of all the coupled wheels is better preserved, with seemingly a slight gain in adhesion.

The nave of the wheel for receiving the axles was formerly bored out conically and the axle turned to suit, the end of the axle being finished flush, over which was placed a brass plate; this plan is highly objectionable, for should the wheel become loose on the axle the covering plate hid the defect; and there can be no doubt that a cone is a great source of danger, for should the axle become loose the contact is at once broken. It is imperative that the hole should be made quite parallel and cylindrical, and the raised part of the axle turned slightly larger, the wheel being forced on the axle with a powerful hydraulic machine; the axle then acts as a mandrill, incorporating as it were the two metals together, the key way being of course cut before the wheel is finally fixed.

The axles are quite plain. Some, indeed, are parallel bars with no collars turned on, while in others deep collars are left bearing on the inside of the axle boxes, two being required for each axle.

The holes for the crank pins are bored out with a machine for the purpose, and are not finished until the wheels have been placed on the axle; by this means they are bored out with a boring bar truly with one another; the hole is quite parallel, and the pin is forced in with an hydraulic machine and rivetted over in the inside; on the outside the hole is recessed about ½ inch, a collar being left on the crank pin; all the other collars are formed on the pin, no loose washers being used. The pin is made much larger where it enters the wheel, as the overhang of the coupling rod is considerable, and the pin requires to be strengthened accordingly.

Framing and axle boxes, bogie frame, &c.—The framing very generally adopted is that known as the trussed beam formerly used by some British makers, but which has now become obsolete in British practice. The bars forming the beam are about 4 inches wide by 2 inches in thickness laid upon the flat side. The horns by which the axle boxes are guided are forged on, and in some instances a separate forging or a casting is bolted to the top bar, forming part of the trussed beam. The bottom of the horns are connected together with a flat bar which extends the entire length of the framing, thus forming a trussed beam the whole length of the engine. The framing is connected to the boiler with braces about 3 feet apart, which is calculated to stiffen the frame; at the same time these braces must be so arranged as not to throw an undue strain on the boiler plates, or otherwise the braces must yield with the expansion and contraction of the boiler, more especially as the boiler plates are not so thick as in British locomotives. These intermediate braces are bolted firmly to the frame and are rivetted to the boiler, broad palms being forged on the end of the tie braces. At the fire-box end a long angle-iron piece is secured to the outer fire-box shell, the boiler at the fire-box end being supported by this means, the angle iron resting on the top of the frame, to which it is secured by means of a strap which is bolted down at the ends to the frame, provision being made for the free expansion of the boiler, say ¼ inch for the whole. The boiler is rigidly held at the smoke-box end, but is quite free to expand towards the back end. The screw bolts for securing the angle-iron brace to the fire box pass through the water space, and are screwed and rivetted to the shell of the inside fire box, and in some a nut having a concave face is screwed. A packing of canvas and red lead is placed upon the bolt before it is screwed through the inner shell; the nut is then tightly screwed against the inside plating of the outer fire box, thus making a perfect joint. The plate-beam frame, 8 to 9 inches deep and 1 inch in thickness, so universally used in British practice, is now adopted by American engineers; this form of frame combines strength and simplicity, giving a ready means of attachment to the various parts, and should have the horns, &c., forged on the plate beam.

The axle guards or horn plates, as has been stated, are welded on, and in some instances cast-iron and wrought-iron pedestals are bolted to the frame, while in the plate-beam frame they are forged along with it. The wearing surfaces of the axle boxes are of cast iron, and sometimes of composition metal, and slide on wedge pieces secured by bolts and confined with the flanges on the axle box. These wedges adjust the wear of the boxes, and coupled engines should never be without some such means of adjustment. A good plan consists of a wedge or shoe piece of cast iron embracing with flanges the side of the horn plate, presenting a surface of say 5 inches. The flanges of the axle box extend upwards, completely inclosing the opening between it and the under side of the frame; they support a short roller above, on which the spring rests, providing a fair bearing no matter what the inclination may be.

The brasses for the axle boxes are lined with anti-friction metal, but this is not desirable in some instances, as grit and dust, finding their way to the journal, soon destroy the rubbing surface. A composition of 97½ parts zinc and 7½ parts copper has been successfully used, the boxes in many instances being entirely cast with this metal, no separate lining brasses being required. The best brass bearings are made of a composition of 9 of copper to 1 of tin, which gives great satisfaction. The lubricant generally used is oil, and never grease, provision being made in the oil boxes for supplying a constant drop by means of siphon wicks.

The front beam of the main framing is of wood, while the back or drag beam is formed by a frame of cast iron placed between the longitudinal main frame pieces, to which it is secured; in other examples the drag beam is constructed of wrought iron.

The engine and tender are coupled closely together, and a cast-iron wedge with tapered plate is fitted on the back of the engine

AMERICAN LOCOMOTIVES.

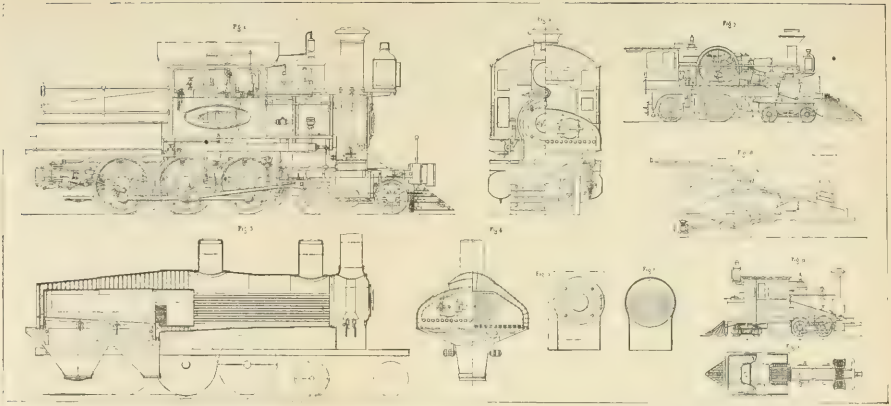


Fig 1. Longitudinal elevation of Freight Locomotive (Wootten System, for anthracite), on the Philadelphia and Reading R. R.

Fig 2. Front elevation and Rear elevation.

Fig 3. Longitudinal section.

Fig 4. Fire Box. Rear View and transverse section.

Fig 5. Smoke Stack. Front View.

Fig 6. Boiler. Transverse section.

Fig 7. High-speed Locomotive (Fontaine System).

Fig 8. Drawing of High-speed Locomotive (Fontaine System).

Fig 9. Elevation of Locomotive Tender (Forney System).

Fig 10. Plan of Locomotive Tender (Forney System).

frame, which is screwed up tightly. Draw springs are never used between the engine and tender, but a draw spring at the back of the tender is at times adopted.

The front beam is generally stayed to the boiler at the smoke box, and sometimes to the main framing; this is required to stiffen the overhanging frame, which is projected in front to clear the truck or bogie wheels.

The bogie frame or carriage is similar in construction to those already described in British practice; some are made with two bearings for each axle placed inside of the wheels, while others have four bearings, two inside and two outside of the wheels. The truck has generally a central bearing, swivelling on a pin, and in some a flat plate is used. In others swivelling takes place on a joint several feet behind the smoke box; the truck has the ordinary central bearing pin, which drives the carriage forward along with the engine. The back end of the truck frame is connected to a swivelling joint in front of the driving axle by means of two radial bars.

When the engine is running on a straight line the truck is held steadily in position by means of inclined seats, upon which the weight of the forward part of the engine rests, and on taking a curve the truck slides laterally on these seats, the axles and wheels adjusting themselves radially or nearly so to the curve, which is a considerable advantage, and the engine runs more steadily on a straight part of the line with this arrangement.

Cowcatcher.—The cowcatcher takes the place of the rail guard in British engines; but it is more formidable in its character, as it can remove quadrupeds straying upon the line, and with the train going at 30 miles an hour it does so safely and with very little ceremony. It is generally made of wrought iron in the form of a coned wedge, consisting of a flat wedge-shaped bottom bar placed a few inches above the rails, and extending across and a little beyond the rails. A strong central brace connects the front of this wedge-shaped bottom bar with the front beam of the engine, while a number of bars about 5 inches apart placed horizontally, and in some inclined upwards, likewise form braces between the bottom plate and the side plate of the cowcatcher, and the forward beam of the main framing as the case may be, thus forming a strong guard, which is likewise stiffened with a rod on each side, connecting the bottom bar with the main frame of the engine. The drag link is a long bar connected to the central bar of the cowcatcher or to the front beam in a strong and substantial manner. There are no buffers placed in front of the engine. (See Figs. 538, 538A, p. 663, 664.)

Cab.—The cab or covering for the protection of the engineman and fireman, which is placed over the foot plate, and partly over the back end of the fire box, is in the form of a house, having a curved roof, the clear height from the foot plate being about 6 feet 6 inches. The frame work is strongly put together, having windows at the front and sides; the front windows can be opened at pleasure for the attendant passing through to lubricate the machinery. Seats are provided with cushions, and in cold weather a screen of canvas is hung up at the back end, so as to thoroughly protect the men from the cold. As might be supposed these house coverings are got up in superior style, both as regards architectural design and the variety of choice woods used in their construction; and along with the rest of the engine they are superbly decorated and painted. (See Figs. 538, 538A, p. 663, 664.)

Inside of the "cab" there is placed a large gong or flat bell, fitted with a spring hammer, so constructed that by pulling a trigger the gong is sounded. A strong cord is attached to the trigger, and is carried back throughout the train. Each carriage, or car as they are termed in America, carries its own length of cord, which can be coupled and uncoupled very quickly by means of spring hooks. The cord is within reach of the passengers, and by pulling it gives a stroke on the gong, which is the signal for stopping the engine, and consequently the train of carriages.

Springs and equalizing beams.—The springs are very similar in construction to those used in British practice. The ends of the spring are formed flat, and the harness consists of a looped strap, which is connected to the framing in the usual manner. In some the top plate is made much thicker at the ends and hollowed out, the spring harness or strap resting in the hollow, by this means keeping the harness in position. The steel plates used in the construction of springs are very seldom more than ⅜ of an inch in thickness, and in some cases only $\frac{5}{16}$ or ¼ of an inch. Pintles or spring pins are used for taking the bearing on the axle box, and in some arrangements a roller is carried on the top of the axle box, the flanges of the axle box extending upwards for this purpose; the strap at the spring centre rests on this roller, which is calculated to give a true bearing, with any inclination due to the working of the spring when the engine is running.

At the end of the spring which is connected to the equalizing beam a slot is cut through the plates for taking a flat link, which is secured with a key at the top, the bottom double link or hoop taking the end of the equalizing beam. When the driving wheel is placed in front and the trailing wheel behind the fire box, the pin for the equalizing beam is carried on a bracket secured to the side of the fire box and framing. With the view of increasing the elasticity of the spring hanging blocks of india rubber are interposed between the frame and the straps holding the springs, although this material is never used for direct springs. In some examples the equalizing beam is formed as a spring, with the view of giving greater elasticity to the hanging arrangement.

Feed pumps, pipes, &c.—The stroke of the feed-pump ram is the same length as that of the piston, the ram being secured to the piston-rod crosshead with a single nut; the end of the ram passes through a snug cast along with the crosshead. The pump is bolted to the frame at the back end; and at the front or gland end it is secured to the bracket plate for carrying the motion bars; this is the plan usually adopted when the cylinders are placed horizontally, and the pumps arranged inside, which is generally done. The barrel of the pump is sometimes cast in brass, with a plunger of wrought iron; but we certainly think that a cast-iron barrel and a Muntz metal ram, such as used in British practice, is to be preferred, though there can be no doubt that a pump cast in brass is more compact, and probably better able to bear the strain should the water in the pump freeze in winter when the engine is cold. The valves are usually of the cup form working in a suitable cage; the lift of the suction valve is generally limited to $\frac{1}{4}$ of an inch, and the delivery valve from $\frac{1}{8}$ of an inch to $\frac{3}{16}$ of an inch rise. The check valve on the boiler is of the same construction, and the valve box is fitted with a gland and stuffing box for taking the pipe from the pump.

The valve boxes both for the suction and delivery pipes are each fitted with an air vessel; with the former it assists the water in its passage to the pump, tending to fill the barrel more readily; while for the delivery valve, the shock that is often felt and heard in all quick-going pumps is reduced to the minimum, thus tending to lessen the necessity for repairs, which are otherwise often required in the feed pipes. The bottom of the suction branch on the pump is fitted with a gland and stuffing box, so that the suction pipe may give with the expansion and contraction of the pipe, when the feed water is warm or comparatively cold. There is always a plug tap fitted to the boiler with pipe connection to each pump and feed pipe; by this means steam is admitted into the pumps in the winter time when they are in danger from the water freezing, as likewise the steam can be admitted into the tender through the suction pipe to heat the water in the tender, and consequently effect a saving in fuel. This can generally be done when running slowly or standing at a station, otherwise the steam would be blown to waste through the safety valves. Water heaters have been tried with a measure of success, the feed water being heated by the waste heat in the smoke box.

The connection between the tender and the suction pipe on the engine which is universally preferred is a plain flexible hose, which bends and unbends with the motion of the engine and tender, the material used in its construction being india rubber and canvas, with a coiled wire placed inside to prevent the pipe collapsing, and which springs readily with the motion. A small plug tap is placed between the delivery valve and the non-return valve on the boiler for relieving the pipe from any steam that may accumulate, and which is worked by a rod (having a handle at the end) passing along to the platform.

THE LOCOMOTIVE TENDER.

THE BRITISH TENDER.

The tender is the vehicle which accompanies the locomotive engine, and carries the fuel and water, &c., required by the leading machine, besides in many cases providing the brake power for controlling the train. The framing of the tender in many examples is entirely composed of wrought iron, built up in some, or in one plate with all the parts cut out; while in others the side frame is of oak, with thin side plates all in one piece, with the guard plates for the axle boxes cut out in the plates, and in some arrangements separate from the side plating; the end beams being formed of oak strengthened with wrought-iron plates. The guide plates are of cast iron bolted between the thin side plates. The axle boxes are of the same material, with a top bush of brass and a bottom part of cast iron, which is held in the axle box with two pins; the ends of the axle boxes are capped to exclude dust and grit from the journals. There are generally six wheels placed under the tender, but some have only four; of course the number of wheels depends on the size or length of the tender, although we find equal lengths have in some cases six and in others four. Four wheels placed closely together will take curves more readily than the six-wheeled arrangement, but the wear and tear of the four wheels must be greater, owing to the carrying weight being more on each, and certainly we think the brake power not so effective as with the six wheels. The various parts of the wheels, namely, the boss, arms, and inside tyre, are forged all in one piece, while in some the boss, arms, and inside tyre are of cast iron, the outside tyre being shrunk on in the usual manner. The springs are placed on the top of the framing, and connected thereto with plain side links, or harness as it is technically termed; the strap at the centre of the spring has the usual bearing pin for supporting the load, the end resting in a recess on the top of the axle box, which prevents the pin shifting. Sometimes the springs are located underneath the side oak beams, placed between the thin plates; with this plan the harness and bearing pin are much shorter than in the other.

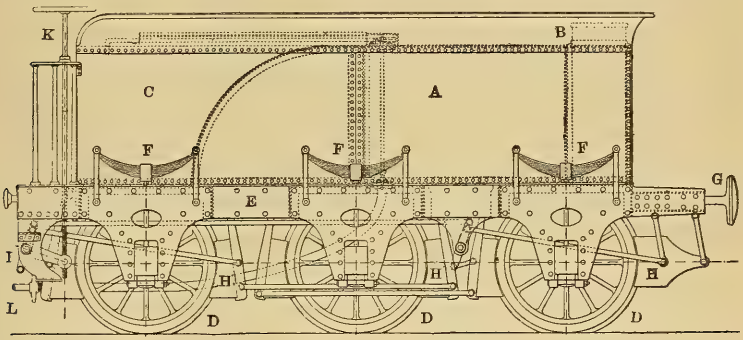


Fig. 538B.—Tender for Passenger Engine.

A, Water space. B, Manhole and water pipe. C, Coal space. DD, Wheels. E, Frame. FF, Springs. G, Spring buffer. HH, Brake blocks. I, Lever screw and rod for brake. K, Hand wheel. L, Pipe connection to the engine.

The brake power is a screw and lever arrangement, with rods connected to arms carried by a top joint fitted to the framing, one being placed at the front and back of each wheel. These arms carry wooden blocks, which are forcibly pressed against the tyres with the screw and lever apparatus. Willow is considered the best wood for the purpose, as it grips firmly and is noiseless. The best result attained is when the wheels are barely kept from skidding, that is, when they are turning round with difficulty, being held by the friction of the blocks acting on the tyres. The leverage is usually about 500 to 1, that is to say, the blocks move towards the wheels with a reduced speed of $\frac{1}{500}$ of the speed of the handle or screw; this, we will allow, is suitable for a weight of tender of 12 tons. This gives a leverage of, say, 41 to 1 per ton of load: thus any weight of tender multiplied by 41 will give the power required. To distribute the strain of the brake, preventing an undue stress on any particular part of the framing, the motion should be reduced with the system of levers beyond the screw; the screw should have a coarse pitch double or triple threaded, and the lever actuated by it should be long in comparison with the shorter levers which act on the brake blocks. We will now take examples from practice, and show what is considered the better arrangement:—

Proportions.

	No. 1.		No. 2.	
Radius of hand lever or wheel, ...	12	in.	7	in.
Pitch of screw, ...	⅓	,,	½	,,
Length of lever for screw, ...	12	,,	39	,,
Length of levers linked to brake block, ...	6	,,	7	,,

In these arrangements the reduction of speed is effected in the first instance with the hand lever and screw, and secondly by the unequal levers on the transverse shaft which actuated the whole system of brakes:—

Reduction.

No. 1.	(1st), 75 to ⅓,	or 225 to 1 by screw.
	(2d), 12 to 6,	or 2 to 1 by lever.
		450
No. 2.	(1st), 44 to ½,	or 88 to 1 by screw.
	(2d), 39 to 7,	or 5·6 to 1 by lever.
		492·8

It will thus be seen in the first example that the reduction by a long lever and screw of fine pitch is 225, while in the second example it is 88 only; in the latter the motion is reduced beyond the screw by the system of levers, and even gives a greater reduction than the former, the concentration of power in the first example being severe on the framing, which should be avoided as much as possible.

In other examples of brake gear two parallel bars are substituted instead of the levers and rods, having suitable wrought-iron brackets bolted thereto for carrying the willow blocks; the bars are guided, and at the end a rack is formed on each, worked by a pinion, with spindle forged along with it on the end of which the lever for the screw is secured. This lever is formed with a jaw for taking the oscillating nut, through which the screwed rod works, the plain part of the rod being continued to the top of the tender, passing through a hole in a bracket, on the top of which the brake handle or wheel is located. The brake blocks in this arrangement simply move to and from the wheels in a horizontal line, which tends to wear the willow blocks more equally; but we must bear in mind that the concentration of power is very severe on the bracket fitted to the framing, and provision must be made to meet the requirement.—For a description of the Continuous Brake, see p. 689.

The coupling between the tender and engine has already been described in connection with the main framing of the engine. The back of the tender is fitted with a draw hook and spring, the buffers being volute springs placed in suitable circular boxes, while in some the draw spring is extended the whole width between the centres of buffers, the spring acting as the buffing medium, as in ordinary railway carriages. Two safety chains are likewise provided on the back beam to connect with the line of carriages, and are fitted with hooks for attachment to the chains on the first carriage of the train.

The water tank is generally of a horse-shoe form, the space between being for fuel. The capacity of the tank is about 150 or 160 cubic feet, containing from 900 to 1000 gallons of water for ordinary passenger engines, and the capacity for goods engines of the heaviest description about 240 cubic feet, containing 1500 gallons nearly; but it must be borne in mind that these quantities vary with the length of the line. Light tank engines, for example, for short lines have a capacity of about 80 to 100 cubic feet, containing 500 to 600 gallons. The tank should be made of the best iron plates, ¼ inch in thickness, and should be well stayed, as its form is weak, and leakage may occur if it is not strongly stayed. It is provided with a short hollow cylinder fitted with a cover, which is placed on the top of the tank at the back end, the principal use of which is for filling the tank with water, but it is also made of sufficient size for a man to pass through to inspect the inside of the tank.

Two feed pipes are fitted to the front end, and are coupled to the feed pipes from the engine. They are provided with valves for regulating the supply.

It is highly necessary that the water used in a locomotive boiler should be as pure as practicable, and for this purpose all impurities should be got rid of in the reservoir before the water enters the tank.

THE AMERICAN TENDER.

The tenders for American locomotive engines are very different from those of the British type. The tank is of the ordinary form, and contains from 1200 to 2000 gallons of water, and from 1 to 3 cords of wood fuel, occupying a space of 128 to 384 cubic feet. The framing under the tank is constructed of wood, the whole of the weight being carried on two trucks similar to that of the engine; in the forward truck the weight is carried on the centre, and at the back end the load is carried on the sides of the truck; by this means there are three parts on which the load is supported. The brake gear is very powerful, each truck carrying its own system of brakes; the willow blocks are secured to transverse bars of wood, and are carried up with shackles secured to the truck frames, and which are actuated by means of a handle and spindle for a chain winding round, taking a system of levers on the front truck, which draws the willow blocks forcibly against the wheels, with a similar system of levers for the back truck, which is connected to the forward system with a chain; by this means the trucks can swivel without deranging the mechanism. In some examples the brakes are only fitted to the back truck of the tender, and are suspended from the framing. The trucks have each four wheels with axles, having the necessary axle boxes, the guard plates are of cast iron bolted to the frame; the springs are placed on the top of the framing, to which they are secured with suitable harness. A strong chain and shackle is placed at each top corner of the truck frame, the other end being carried by the main frame; these are necessary in order to prevent the trucks swivelling too far.

BRAKES AND REGISTERING APPARATUS.

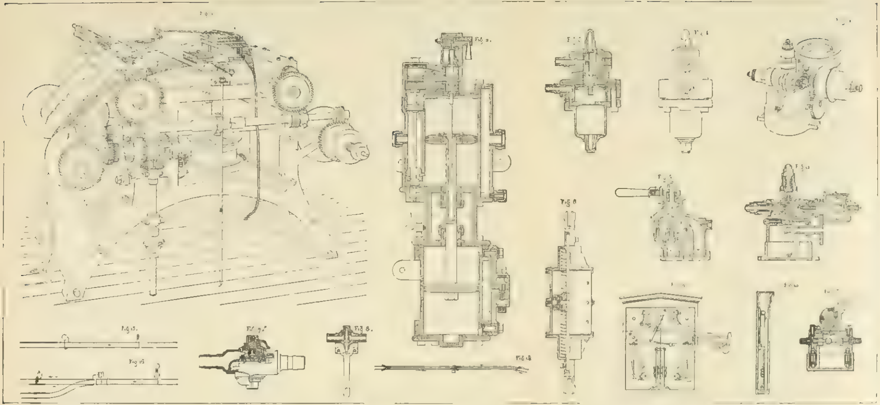


Fig 1 Dudley Dynamograph

Fig 2 Westinghouse Compressed Air Brake Transverse section of Air-Pump

Fig 3 Transverse section of the Triple Valve

Fig 4 Elevation of the Triple Valve

Fig 5 Working or Distributing Valve

Fig 6 Cylinder with double piston Section and Elevation

Fig 7 Combination of Conduit Section and Elevation

Fig 8 Escapement Valve

Fig 9 Pitcairn Apparatus for ascertaining the Condition of the Road

Fig 10 Transverse section of Pitcairn Apparatus

Fig 11 Apparatus for Measuring the speed of Trains Westinghouse System

Fig 12 Longitudinal section of Speed-Registering Apparatus

Fig 13 Transverse section of Speed-Registering Apparatus

Fig 14 Middle Sidings

Fig 15 Signals of the Union Electric Signal Company for through courses.

Fig 16 Signals for Crossings.

CONTINUOUS BRAKES.

In our notice of the Locomotive Tender we have described the construction of the ordinary brake gear as fitted to tenders and brake vans; but the vastly increased traffic on our railways has rendered necessary some more speedy and certain appliance for diminishing the speed of trains and stopping them within short distances. It is now over twenty years since the Board of Trade first urged upon railway companies the necessity for adopting such appliances; and in 1878 a bill was passed enforcing upon the companies periodical returns to the Board respecting their action in the matter of brakes. With a view still further to protect the travelling public a bill was introduced into Parliament in 1882, rendering it compulsory on all railway companies to adopt some form of continuous brake which will comply with the following requirements:—To be instantaneous in action, and capable of being applied by driver and guards; in case of accident, to be self-acting; to be applied to every vehicle in the train; to be in regular daily working; and the materials employed to be of durable character, easily maintained and kept in order. This bill, however, did not become law.

A variety of continuous brakes have been introduced with a view to meet these requirements; and there can be no doubt that the use of such brakes has already been of much service in lessening the risk of accident, as by their means trains which formerly required about half a mile to pull up can now be brought to a stand in about 300 yards. Among the forms of continuous brake which have been tried are Barker's Automatic, Eame's, Fay, Newell, and Eame's Combined, Sanders and Belitho's Automatic Vacuum, the Steel-M^cInnes, Smith's Automatic Vacuum, and the Westinghouse Automatic Brake;—the various arrangements being known as Screw Brake, Chain Brake, Hydraulic Brake, Vacuum Brake, and Compressed-air Brake. In all these forms the whole or part of the wheels of the train can be braked by mechanism actuated from the engine. In the first two methods rigid or flexible bodies are used, in the others fluids transmit the power required. In the hydraulic brake water is forced at a high pressure along pipes. In the air brake air is in a similar manner forced to the point of application, and in the vacuum brake the air is removed.

For automatic arrangements, whether of air or vacuum, there are chambers or reservoirs underneath the carriages. These are fitted with cylinders and pistons, the latter in connection with the brake blocks; the object in such arrangements being to keep up a certain condition in the chambers, whether of pressure or vacuum, which if destroyed either intentionally or accidentally, as by the breaking away of the carriages, the brake blocks will immediately be applied to the wheels.

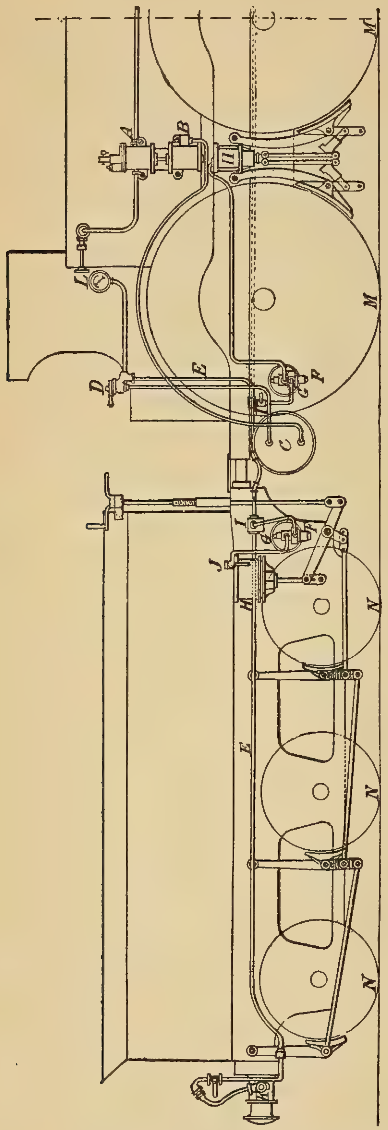


Fig. 538c.—Part of Locomotive Engine and Tender with the Westinghouse Automatic Brake.

A, Steam cylinder. B, Air cylinder. C, Main reservoir. D, Driver's brake valve. E, Brake pipe. F F, Triple valves. G G, Small reservoirs. H, Brake cylinder. I I, Stop valves. J, Release valve. K, Coupling. L, Pressure gauge. M M, Engine wheels. N N, Tender wheels.

The Westinghouse Automatic Brake has now been extensively adopted on the more important railways in Great Britain as well as those on the Continent and in the United States of America. This brake is continuous throughout the train, and is operated by compressed air stored in a main reservoir on the engine, and in small reservoirs, one upon the engine, tender, and each carriage, all connected by a pipe running the length of the train. There are also on each vehicle a triple valve and brake cylinder with pistons connected to the brake levers.

Fig. 538c shows this brake complete fitted to an engine and tender. The pump on the engine is started by admitting steam to the cylinder A, air is forced from the cylinder B into the main reservoir, which is connected to the driver's brake valve. When a train is to be charged—the hose couplings between all the carriages and engine or tender having been united—the compressed air stored in the main reservoir is turned into the brake pipe by putting the handle of the driver's brake valve over to the left. It then fills the brake pipe and flows by a branch pipe through the triple valve into the small reservoir on the tender and each vehicle, where it remains until the brake has to be applied. Uniform air pressure then exists throughout the train except in the brake cylinders, the brakes being off, and the pressure per square inch is shown on the gauge connected to the brake pipe on the engine and in the guards' vans. So long as this pressure is maintained the brakes are kept off, as the passage from each small reservoir to its cylinder remains closed; but letting the air suddenly escape from the brake pipe causes the triple valves to move down and uncover the passages to the cylinders. The air stored in the small reservoirs then flows into the cylinders and forces out the pistons and rods, thus applying the brakes. On the other hand, the brakes are taken off by reopening the passage from the main reservoir, through the driver's valve, and thus restoring the pressure in the brake pipe; this lifts the triple valves, and places the cylinders in communication with the atmosphere by means of an exhaust cavity in each of the valves, at the same time recharging the small reservoirs; the air used in the cylinders is thus allowed to escape, and the brake pistons and rods are pushed back to their places by springs inside the cylinders. It follows from the above that any sudden *decrease* of pressure in the brake pipe, whether produced by the driver or guard operating his brake valve, or by the separation of the train, or other accidental severance of, or damage to, the brake pipe, *applies* the brake. It is therefore called "automatic" or self-acting; and owing to this principle the brake acts as a "tell-tale" as to its own condition, for should anything be wrong a warning is unmistakeably given by stopping the train. Special provision is made to prevent the application of the brake from leakage, and a release valve is fitted on each cylinder for the purpose of releasing the brake direct, if applied when an engine is not attached.

Fig. 538D shows the Vacuum Automatic Brake which is adopted on many of our railways. This form of brake is operated as follows: By means of a small steam ejector placed upon the engine the air is drawn out of the main train pipe E, from the bottom side of the piston or diaphragm A through the branch pipe F, and from the vacuum chamber B and top side of piston or diaphragm through the valve D, so that a vacuum of 20 to 24 inches (*i.e.* 10 to 12 lbs. per square inch) is maintained throughout the system. To apply the brake a valve is opened by the driver or guards, which allows air to flow to the bottom side of the piston or diaphragm, the top side and vacuum chamber maintaining the vacuum through the action of the valve D, which closes immediately air is admitted to the train pipe. To release the brakes when the engine is detached from the train, the valve D is raised by means of a small lever placed on either side of the carriage which admits air to the vacuum chamber and top side of piston or diaphragm, and the brakes fall off by gravity. The flexible diaphragms, hose pipe connections, and miniature sacks C are made of the best rubber and coated with a material which effectually resists oil and grease.

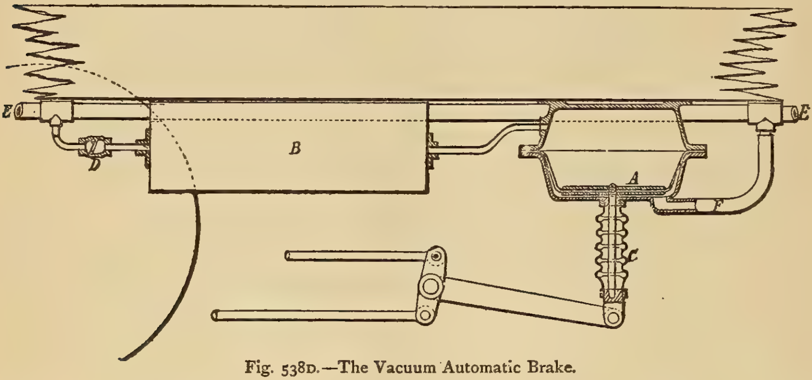


Fig. 538D.—The Vacuum Automatic Brake.

BRAKE RESISTANCES.

From a series of experiments made by Captain Douglas Galton, C.B., F.R.S., on the effect of brakes upon railway trains, some curious and interesting results have been obtained, from which it appears that—

(1.) "The retarding effect of a wheel sliding upon a rail was much less than when braked with such a force as would just allow it to continue to revolve." The resistance due to friction of the wheel on the rail being only one-third of the friction between the wheel and the brake blocks.

(2.) "The coefficient of friction between the brake blocks and the wheels varied inversely according to the speed of the train." Thus with cast iron brake blocks on steel tyres the coefficient of friction when just moving was ·330—

At 10 miles per hour,	·242	At 40 miles per hour,	·140
,, 20 ,, ,,	·192	,, 50 ,, ,,	·116
,, 30 ,, ,,	·164	,, 60 ,, ,,	·074

Further, it was found that this coefficient was affected by time, thus: Starting at 27 miles per hour the coefficient was ·171; after 5 seconds, ·130; after 10 seconds, ·119; after 15 seconds, ·081; and after 20 seconds, ·072; and at 47 miles per hour the coefficient at starting was ·132, falling after 10 seconds to ·070; and at 60 miles per hour falling from ·072 to ·058.

These coefficients are further influenced by material and weather. It was found that the distance run by a train on the level at 50 miles per hour varied with the percentage of the total weight of train used for retardation as follows: with 5 per cent, 555⅔ yards; 10 per cent, 277⅔ yards; 20 per cent, 139 yards; 30 per cent, 92⅔ yards.

Capt. Galton points out amongst other conditions that a perfect continuous brake should be fitted to act upon all the wheels of engine and carriages, that it should exert upon the blocks of each pair of wheels within two seconds a force of about twice the load on those wheels, that the brake-block pressure should be such that the friction between the block and wheel may not be greater than the adhesion between the wheel and the rail, and that the action should be automatic in the event of a separation of the train or failure of connections.

COMPOUNDING LOCOMOTIVE ENGINES.

The principle of compounding has been recently applied with good results to the locomotive engine, and thereby enables the benefit of expansion to be more fully carried out than could be with the single cylinder. One of the arrangements consists in having a high and low pressure cylinder, one on each side of the engine, so that instead of two independent cylinders of the same size, having steam to each from the boiler, the steam first enters the high-pressure or smaller cylinder and thereafter passes across to the low-pressure or larger cylinder.

This system was introduced on some of the French lines a few years ago by M. Anatole Mallet, and appears to have been successful there. In a paper read by that gentleman before the Institution of Mechanical Engineers he says:—

"The compound system affording a simple and effective means of expanding, that expansion should be carried to a high degree, and for this purpose cylinders of a large size must be used. In new engines this can easily be done. The application of the compound system to existing locomotives is much more difficult; if some engines lend themselves readily to the change, this is by no means the case always. The author is convinced that the system will be further extended; and its success, he is satisfied, would be speedily assured, if a thorough practical trial were made on one of the English railways."

"The usual method of converting an existing engine is generally to retain one of the original cylinders as the high-pressure cylinder, and to replace the other by a new one of larger diameter for expanding; the steam and exhaust pipes are suitably rearranged, and a starting valve and reducing valve are added, while the whole of the original mechanism is retained for the large cylinder. The first engines altered in this way were two powerful locomotives, one a passenger

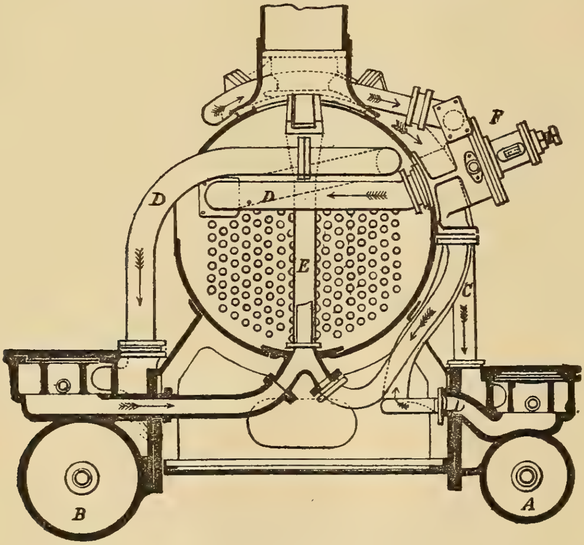


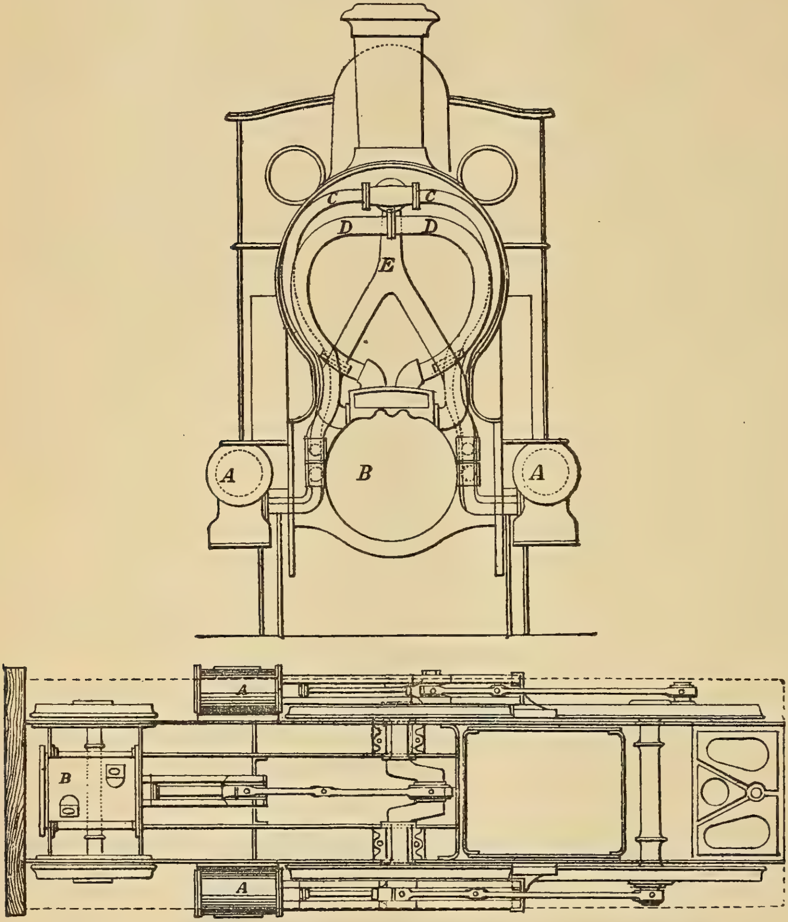
Fig. 538E.—Engine with right-hand Cylinder altered.

A, High-pressure cylinder. B, Low-pressure cylinder. C, Steam pipe. D D, Exhaust pipe from the high-pressure cylinder. E, Blast pipe. F, Safety valve on the starting-valve chest.

engine on the Paris and Orleans Railway, and the other a goods engine on the Northern Railway of Spain. The arrangement of this altered engine is shown in Fig. 538E. The old cylinders were 17⅜ in. diameter and 23⅝ in. stroke; of these the right-hand one has been replaced by a cylinder of 23⅝ in. diameter, which was as large a size as the engine frames would allow to be got in; the ratio of the two piston areas is therefore 1·86 to 1. The exhaust pipe from the small to the large cylinder is made to take a long winding course, so as to get as large a capacity of receiver as possible, amounting in this case to 1·69 times the capacity of the small cylinder; by the same means also the pipe has about 20 square feet of surface exposed to the heat of the smoke box. As the alterations were required to be made in the simplest and least expensive manner possible, the arrangement of the two link motions to work independently of each other has not at present been carried out in this engine, which is the more to be regretted as it presented no special difficulties; but it can be done at any future time. The reducing valve has been fitted with a spring to prevent any violent shocks in case of its acting too quickly; and a spring safety valve has been fixed on the starting valve chest, to avoid excessive compression of the steam when working reversed."

A trial of this principle has now been made by Mr. Webb of Crewe, who has recently designed and placed on the London and North-Western Railway a new compound locomotive which appears to have given most satisfactory results. We are indebted to that gentleman for the elevation and plan of this locomotive shown on the following page.

"The new engine has been constructed at Crewe, and is similar as regards boiler, wheels, and so on, to the four-coupled express engines of the London and North-Western Railway. The trailing drivers are driven by a pair of outside cylinders 11½ inches diameter and 24 inches stroke, secured to the side frames at a point just in advance of the leading driving wheels. The piston-rod heads are guided by two flat bars, one at each side, instead of four, as usually employed, the crosshead being channelled to slide on the bars. The slide valves are worked by Joy's patent gear, and the connecting rods lay hold of pins in the wheel bosses. So far we have a complete engine with outside cylinders and a pair of driving wheels behind the fire box, resembling Crampton's patent engine. In the smoke box, right beneath the funnel, is fixed a third cylinder, 26 inches diameter and 24 inches stroke, the connecting rod of which lays hold of the pin of a single crank in the middle of the length of the leading driving axle. The exhaust steam from the two small cylinders passes into a kind of gridiron of pipes between the engine frames, which pipes act as an intermediate receiver, and from thence it is led into a copper pipe coiled in the smoke box, in order that it may be reheated and dried. Thence it goes into the valve chest of the large cylinder.



Figs. 538F, 538G.—Front End Elevation and Ground Plan of Compound Locomotive, London and North-Western Railway.

A A, High-pressure cylinders. B, Low-pressure cylinder. C C, Steam pipes. D D, Exhaust pipes from high-pressure cylinders. E, Blast pipe.

We have thus a locomotive with a single pair of driving wheels in advance of the fire box, driven by a single cylinder. It must be understood that the double engine and this single-cylinder engine are quite independent of each other—that is to say, each may run at any pace it can. There are no coupling rods, nor is there anything to maintain a fixed relative position between the cranks of the single and double cylinder engines, save the rails. The single engine depends for its supply of steam on the double-cylinder engine, and should the latter slip, more steam is sent into the receiver than the large cylinder will take, and the back pressure rises, and so tends to check slipping; while for the same reason the pressure on the large piston is augmented, and it may slip its wheels. If, on the contrary, the single engine slips first, it will take more steam away than the other engines can supply, and its own pressure will fall off while the effective pressure in the other cylinders will be augmented. It is found that this controlling action operates very effectually, each engine doing its own share of the work fairly. No inconvenience results from the changing position relations of the crank pin, the size of the intermediate receiver being sufficient to prevent irregularities in the amount of back pressure of much moment. With a boiler pressure of 150 lbs. the pressure in the receiver averages about 50 lbs. This compound locomotive is a handsome engine, and has been run at very high speeds with perfect steadiness. Mr. Webb states that the engine works ordinary passenger trains with a little over 23 lbs. of coal per mile, which represents a saving of perhaps 20 per cent. in fuel on the ordinary consumption. It is beyond question the best type of compound locomotive ever constructed, and we shall be much surprised if a large number of such engines are not soon put into regular traffic."[1]

As already stated, the valve gear employed in this compound engine is Joy's, the ordinary link motion not being considered in this case satisfactory. This valve gear is described as follows: "In a kind of box under the running board is fitted a disc, which may be said to resemble the plug of an ordinary stop cock. In this plug is a curved slot, having the same radius of curvature as the length of the link leading from a die in this slot to the end of the valve rod. This link is coupled to the connecting rod by two bars. The effect is that as the crank shaft revolves the die is caused to travel up and down in the slot in the plug. If the slot is set at angle with the vertical, the valve stem will obviously be caused to move backwards and forwards; when, however, the slot is vertical the valve has no motion imparted to it by the travel of the die. The plug has a lever arm attached to it answering to the handle of a tap. This lever is coupled to a reversing lever with quadrant. By this means the plug can be made to partially rotate, and so alter the angle of inclination of the slot that the engine will run forward or backwards."

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[1] *The Engineer*, Aug. 1879, Feb. Mar. 1882.

DESCRIPTION OF SPECIAL LOCOMOTIVE ENGINES.

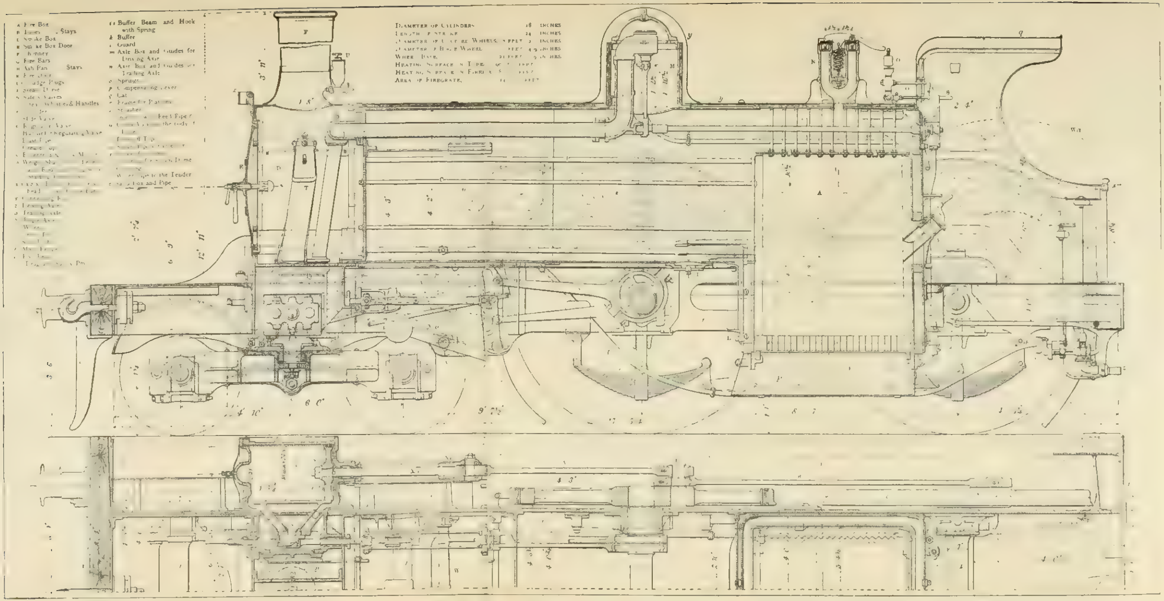
FOUR-WHEEL COUPLED BOGIE PASSENGER ENGINE FOR THE CALEDONIAN RAILWAY. (See Plates.)

The boiler is of the best Yorkshire iron, plates ½ inch thick in the barrel, tube plate $\frac{13}{16}$ inch, firebox casing sides $\frac{9}{16}$ inch, back ½ inch, and front ⅝ inch thick. The longitudinal seams are top-jointed and double rivetted, and the transverse seams single rivetted with $\frac{13}{16}$ inch rivets placed 1⅞ inch between the centres. The inside firebox is of the best copper ½ inch thick, except the tube plate, which is ⅞ inch thick where the tubes are fixed, and ½ inch below. The casing and firebox are stayed together at the ends and sides with 1 inch copper stays, screwed into both plates, and placed 4 inches apart between the centres. The roof is stayed with iron through stays 1⅛ inch diameter screwed through both plates, rivetted on the outside and secured with nuts inside. The tubes are of copper 1¾ inch diameter and swelled to $1\frac{13}{16}$ inch at the smoke box end, 13 W. G. thick at the fire box and 12 W. G. at the smoke box, fixed in the fire box tube plate with solid drawn steel ferrules 10 W. G. thick.

The frame is of Yorkshire iron 1⅛ inch thick over the driving and trailing axles and 1½ inch thick over the bogie. The bogie frame is 1 inch thick.

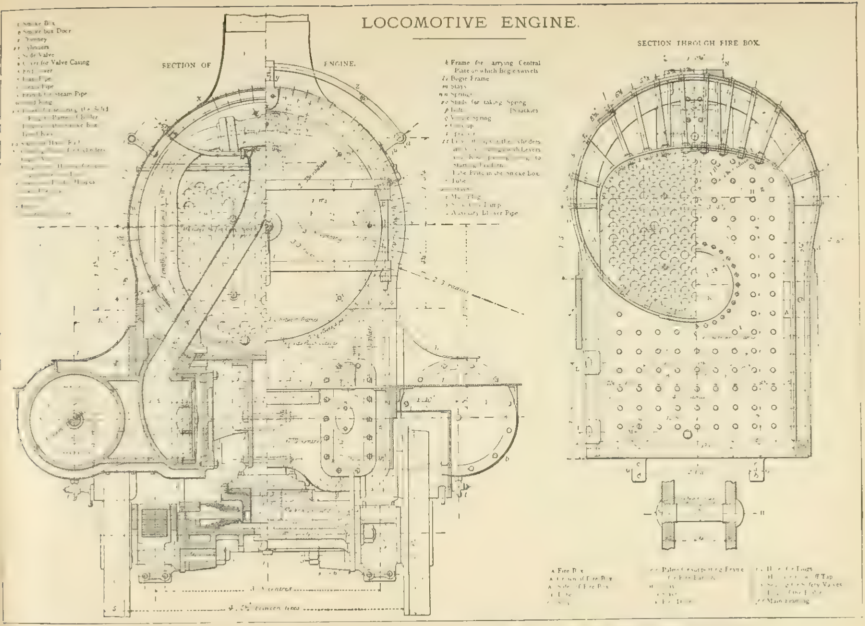
The driving and trailing axle-box guides are of steel, of a horse-shoe form, and securely bolted to the frames; the bogie guides are of cast iron. Driving and trailing axle boxes are of cast iron with gun-metal steps and keeps. The bogie axle boxes are of gun metal with cast-iron keeps. The bearings in all cases are lined with white

LOCOMOTIVE ENGINE.



VERTICAL AND HORIZONTAL SECTIONS OF BOGIE PASSENGER ENGINE.

LOCOMOTIVE ENGINE.



TRANSVERSE SECTIONS OF BOGIE PASSENGER ENGINE. BUILT FOR THE CALEDONIAN RAILWAY BY MESSRS. NEILSON & CO., GLASGOW.

metal. The axles and tyres throughout are of crucible cast steel. The crank pins are of Yorkshire iron well case-hardened in the journals.

The slide bars are of Bessemer steel. The piston rods are of best Yorkshire iron. The connecting and coupling rods, crossheads, and the whole of the valve motion, including eccentric straps and the smaller parts of the pulleys, are made of best Yorkshire iron and well case-hardened where required. The larger parts of the eccentric pulleys are of cast iron. The cylinders are of a mixture of cold blast and Scotch pig iron twice melted and as hard as possible. The pistons are of the same metal, with two cast-iron rings in each.

The wheels are of the best scrap iron, with cranks and balance weights forged solid in them. The tyres are secured with clip rings on the sides recessed into the rim of the wheel as well as the tyre, and are held in place by rivets passing through the clips and the rim at the end of each spoke. The springs are of the best spring steel converted from Swedish iron.

The ashpan damper, cylinder cocks, and sand boxes are all workable from the footplate.

Two Friedmann's No. 9 Injectors, fitted with check valves and all other necessary valves and cocks, are used for feeding the boiler.

The boiler was tested after all the fittings were attached with water pressure to 200 lbs. per square inch, and carries a working pressure of 130 lbs. per square inch.

The weight when loaded is as follows:—

	Tons	cwts.	qrs.	
Bogie,	13	0	0	(equally divided).
Driving wheels,	14	15	0	
Trailing wheels,	13	12	0	
Total,	41	7	0	
Tender,	27	8	0	Full of water and 3 tons of coal.

Tractive force 90 lbs. for each lb. of effective pressure on the piston.

The tender is carried on six wheels, and contains 1880 gallons of water and 4 tons of coal. The frames are of the same quality of iron as those for the engine, and ⅞ inch thick. The tank is of best Scotch iron plates, top and bottom $\frac{5}{16}$ inch and sides ¼ inch thick well stayed. The wheels are of the same description as those for the engine, and fitted in a similar manner with tyres of Bessemer steel.

The axles are of Bessemer steel; the axles boxes and guides of cast iron fitted with steps of gun metal. A powerful brake worked by a screw from the footplate acts upon each wheel.

EXPRESS ENGINE FOR GREAT NORTHERN RAILWAY.[1]

In the next example to which attention is directed, outside cylinders have been used; perhaps as a necessary consequence of the adoption of a bogie carriage with four wheels, instead of a pair of leading wheels, to insure greater freedom in passing round curves at high speeds, for which special object the engine has been designed by the locomotive engineer of the Great Northern Railway. The weight on each of the four front wheels is at the same time proportionately diminished, and with great advantage. It will be observed that there is one frame only on each side of the fire box and inside the wheels, and that this frame receives the cylinders. These frames are of one solid plate, 1¼ inch thick, connected behind the fire box by a cast-iron cross frame, and elsewhere by wrought-iron cross brackets and by the buffer beam, receiving the cylinders in front on each side of the smoke box. This position gives convenient access to the cylinders, the pistons and rods, the connecting rods, the guide bars, and the motion blocks, all of which are placed outside the

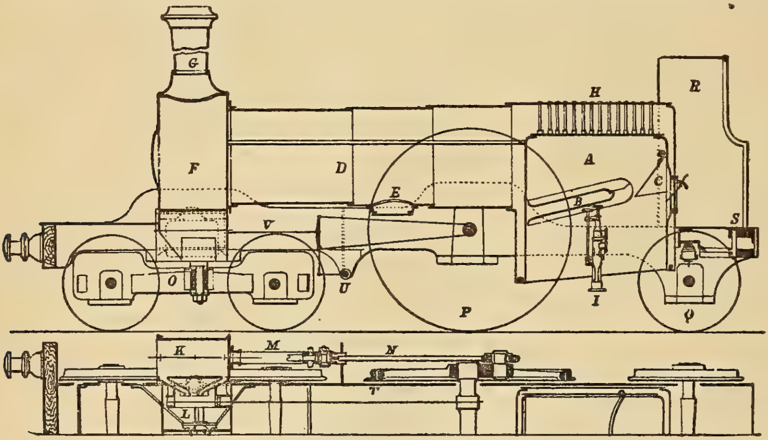


Fig. 539.—Express Engine for Great Northern Railway.

A, Fire box. B, Midfeather. C, Fire door and deflecting plate. D, Body of boiler. E, Mud chamber. F, Smoke box. G, Chimney. H, Stays. I, Injector. K, Cylinder. L, Valve chest. M, Guide bars. N, Connecting rod. O, Bogie carriage. P, Driving wheel. Q, Trailing wheel. R, Cab. S, Draw pin. T, Frame. U, Weigh shaft. V, Line of valve spindle.

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[1] *Transactions of the Institution of Civil Engineers.*

frames. The slide-valves and their gearing are inside the frames, though somewhat nearer to them than in inside-cylinder engines. The train is drawn from the cast-iron cross frame, which, together with the longitudinal frames, is so attached as to allow of the free expansion of the boiler, to avoid any strain being put upon the latter by the haulage of the train, and to free it from the contortions formerly occurring when rigidly connected with the frames at several points. The proper adjustment of the driving axle boxes is secured by wedge-shaped horn blocks, attached to the frames by a screw with lock nuts. The boiler is made of Yorkshire plates, ½ inch thick, and is of the lap-jointed class, having double-rivetted longitudinal and single-rivetted vertical seams. The pressure of steam employed is 140 lbs. to the square inch.

The fire box is of copper, the tube plate being ¾ inch thick, the back plate ⅝ inch thick, and the sides and crown ½ inch thick. It is of the usual square form, and is attached to the external iron shell by a square iron frame at the bottom; and at the front, sides, and back by screwed copper bolts, rivetted at both ends. The roof is stayed to the external shell by wrought-iron radiating stays, ⅞ inch in diameter, screwed into the copper plates and into the iron casing. The fire box contains a sloping midfeather in such a position as to deflect the heated gases from the fire before they reach the tubes. The air admitted through the fire door, and directed by the ordinary deflecting plate, is thus thoroughly mixed up with the heated gases, thereby securing the best possible combustion.

The boiler is fed by two injectors, and the water can be supplied without reference to the motion of the engine. The tubes are of brass, 217 in number, and each $1\frac{9}{16}$ inch external diameter. This comparatively small diameter tends to secure the more effectual abstraction of heat from the gases passing through the tubes.

The cylinders are outside the frames; they are 18 inches in diameter and 28 inches stroke, and may be considered a large size for passenger engines. The joint of each steam-chest cover is in the centre line of the valve spindle, so that when the cover is removed ready access to the valve facing is obtained. The valve gearing is of the ordinary shifting-link class. The small ends of the connecting rods are furnished with solid bushes of gun metal, which succeed admirably, the connecting rods having run a distance of more than 50,000 miles without renewal. The driving wheels are 8 feet 1 inch in diameter; and the trailing wheels are 4 feet 1 inch in diameter. The end of the engine is carried upon six volute springs, placed in a trough under the footplate, as being more conveniently got in than the ordinary elliptical springs. There is a cab over the foot plate for the protection of the driver and the fireman.

The front of the engine is carried upon a four-wheeled bogie frame, with a cylindrical centre pin, the hole in the bush being bored taper. It has also sliding bearings in the line of the side frames under the cylinder steam chests, to give greater stability to the engine when running at high speeds. This bogie arrangement imparts flexibility to the engine when passing round curves, and secures the greatest steadiness of the whole machine, at whatever speed it runs.

The mode of attaching the inner to the outer fire box, by stays screwed into each of the plates without the intervention of iron girder bars, though in use for some time in Belgium, is now in some cases adopted in this country. By this arrangement the large amount of deposit generally existing upon girder boxes is prevented, and the facility for cleansing is much greater. The liability of the tube holes in the copper plate to become oval, by the pressure of the ends of the girders upon the edge of the tube plate, is also got rid of. It is understood that no countervailing disadvantages have arisen from the adoption of the system.

The heating surface in this engine is:—

In the tubes, ...	1043	sq. feet.
,, fire box, ...	122	,,
Total, ...	1165	sq. feet.

The fire-grate area is 17·6 square feet.

The weight upon the wheels, when the engine is in working order, is:—

On the driving wheels, ...	15	tons.
,, hind wheels, ...	8	,,
,, bogie, ...	15	,,

The distance from the centre of the hind wheels to the centre of the bogie pin is 19 feet 5 inches.

The engine is capable of drawing a weight of 356 tons on a level at a speed of 45 miles per hour (the load drawn includes in all cases the weight of the engine and tender), with a working pressure of 140 lbs. Its consumption of coal, with trains averaging sixteen carriages of 10 tons weight each, has been 27 lbs. per mile, including getting up steam and piloting; the cost of repairs being about ·52*d.* per mile run. This engine has been designed to fulfil the requirements of a quick and heavy passenger traffic; and in the whole arrangement of the parts, as well as in the excellence of the materials selected for the construction, both durability and economy of repair have been kept in view.

Smaller engines of this class on the same railway have 7-feet driving wheels, with cylinders 17 inches in diameter, with 24 inches stroke of piston.

PASSENGER ENGINE FOR LONDON & NORTH-WESTERN RAILWAY.

The next example of an engine for passenger traffic is one designed for the London and North-Western Railway.

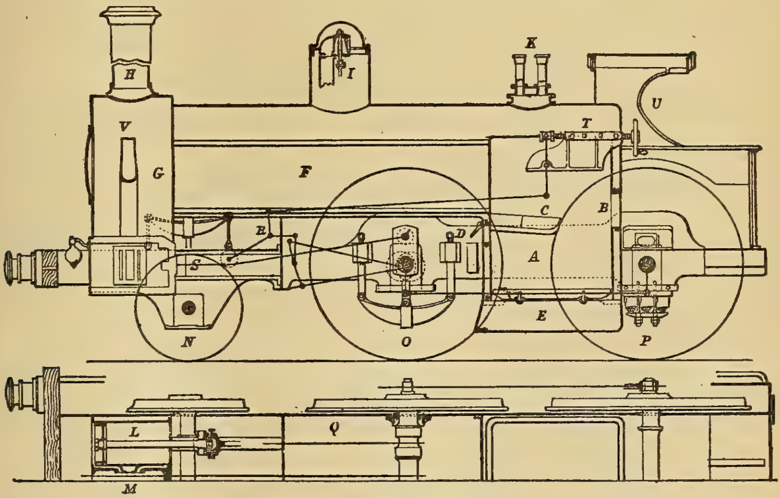


Fig. 540.—London and North-Western Railway Passenger Engine.

A, Fire box. B, Fire door. C, Fire-brick arch. D, Air holes. E, Ash pan. F, Body of boiler. G, Smoke box. H, Chimney. I, Steam chest and regulator. K, Safety valves. L, Cylinder. M, Valve chest. N, Leading wheel. O, Driving wheel. P, Trailing wheel. Q, Frame. R, Weigh shaft. S, Line of valve spindle. T, Reversing wheel and screw. U, Cab. V, Blast pipe

The cylinders are placed inside between the frames, each of which is cut out of a piece of solid plate, 1 inch thick. The frames extend the whole length of the engine, and are connected by the buffer beam, by the cylinders, the motion plate, an angled bracket in front of the fire box, and by a vertical buffing plate and horizontal cross plates behind the fire box. The train is drawn from these frames, which are free to allow the boiler to slide upon them at every point behind the smoke box. The boiler is of Lowmoor plates, $\frac{13}{32}$ inch thick, and is lap jointed. The steam pressure employed is 120 lbs. per square inch, and it is controlled by two safety valves. The fire box is of copper, of the ordinary form, fixed to the external shell by a square iron frame at the bottom, and by copper screw stays placed 4 inches apart, and rivetted over at both ends; the roof being stayed by longitudinal wrought-iron girders, connected to the external shell by vertical sling stays. The fire box contains a fire-brick arch extending backward about half the length of the box. Under this arch are two circular holes, 7 inches in diameter, covered by doors which can be worked from the foot plate, so that the amount of air admitted is well within the control of the driver. The fire doors are of the double lever sliding kind, and invariably secure the admission of air in the middle of the firing hole.

The boiler is fed by two injectors, to the arrangement of which particular attention is directed. They are placed vertically behind the fire box, so as to be easily manipulated by the driver. A vertical screw with a wheel handle regulates the admission of the water to the injector, which ascends and passes through a clack box (that can be closed at pleasure) into the boiler along an internal pipe, carried forward two-thirds of the length of the barrel of the boiler. By this arrangement all external pipes running forward outside the boiler are done away with, and greater simplicity and freedom from accidents are secured.

The boiler tubes are of brass, 192 in number, and each 1⅞ inch external diameter. The cylinders are in the smoke box; they have a diameter of 17 inches and a stroke of 24 inches, the slide valves being placed vertically between them. Each piston is guided by one upper and one lower steel guide bar after the fashion of an outside-cylinder engine. The valve motion is of the ordinary shifting-link class, the valve rods being square at the back part, and working in cast-iron guides. The reversing motion is effected by a screw and fly wheel, to obviate the danger of the lever flying back, as in the ordinary arrangement, and to lessen the effect on the motion of the train when diminishing the admission of steam.

There are four driving wheels, each 6 feet 7½ inches diameter, coupled together by outside rods. The leading wheels are 3 feet 7½ inches diameter. The connecting rods are forked, so as to gain a greater length in proportion to the length of the stroke. The cross-head step bushes are of wrought iron case-hardened. The coupling rods are furnished with circular step bushes of white metal. All the rods are of steel. The end of the engine is carried upon six volute steel springs, three on each side, placed below the axle boxes, all of which are of solid brass, those for the coupled wheels working in steel guides. The total heating surface is 1102 square feet. The fire-grate area is 15 square feet.

Distribution of weight, when in working order, on the leading axle 9 tons 9 cwts., on driving axle 11 tons, on trailing axle 8 tons 15 cwts.; total, 29 tons 4 cwts. Total wheel base 15 feet 8 inches.

FOUR-COUPLED BOGIE PASSENGER TANK ENGINE ON NORTH BRITISH RAILWAY.

In Fig. 541 we give sectional and horizontal views of a new type of engine designed by Mr. D. Drummond, locomotive superintendent of North British Railway. Originally intended to work the company's coast traffic, the engine has been found most useful for branch work generally.

The cylinders are 17 in. diameter, stroke 26 in. There are four coupled wheels, 6 ft. diameter; diameter of bogie wheels 3 ft. 6 in.; total wheel base 21 ft. 1 in.

The boiler barrel is telescopic, 10 ft. 1 in. long, and 4 ft. 4 in. diameter outside of the front plate. It is composed of two rings of plates, each being in one plate. The longitudinal seams are butt-jointed, and secured outside and inside with butt straps, strongest in their transverse section, 7½ in. wide and ⅝ in. thick, double rivetted. The circular laps are 2½ in. wide and single rivetted. The boiler barrel is secured to the smoke-box tube plate by a solid rolled angle-iron ring, 5¼ in. by 3¼ in. by 1 in. thick, double rivetted to the boiler barrel and single rivetted to tube plate. The outside fire-box shell is 5 ft. 5 in. long outside, and 4 ft. 6¼ in. at centre line, and 4 ft. 1 in. at bottom. The depth of the back end below the centre line of the boiler is 4 ft. 4 in. to bottom of foundation ring, sloping to 5 ft. 6 in. at the front end. The corners of the fire-box are made to a radius of 6 in. outside. The sides and top of the fire box shell are made in one plate, flanged, double rivetted at the longitudinal portion only, and single rivetted to the outside shell of the fire-box. The fire door is 1 ft. 1 in. by 1 ft. 4 in., and is fitted with a solid wrought-iron ring 1¼ in. thick by 2½ broad, rivetted with a single

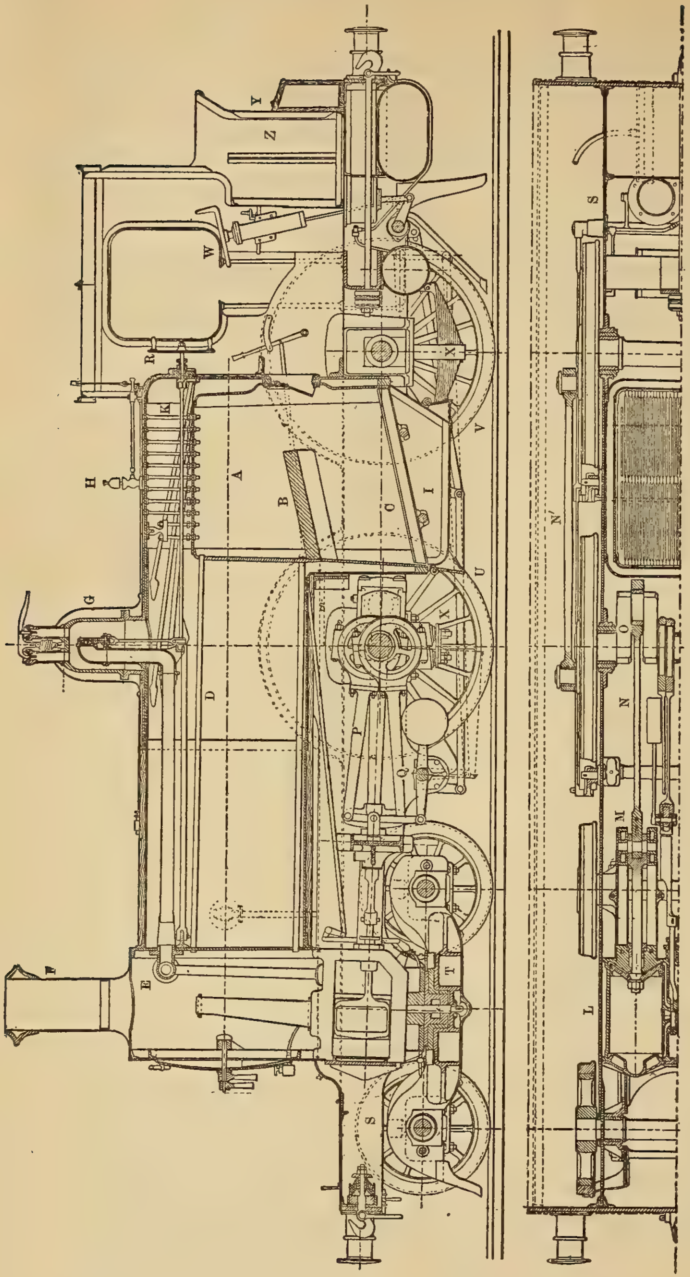


Fig. 541.—Longitudinal Section and Half Plan of Four-coupled Bogie Passenger Tank Engine, North British Railway.

A, Fire box. B, Fire-brick arch. C, Fire bars. D, Tubes. E, Smoke box. F, Funnel. G, Steam dome and safety valves. H, Whistle. I, Ashpan. K, Stays. L, Cylinder. M, Crosshead, motion bars, &c. N, Connecting rod. N′, Side rod. O, Cranked shaft. P, Double eccentrics and link. Q, Weigh shaft. R, Regulator handle. S, Main framing. T, Bogie and wheels. U, Driving wheel. V, Trailing wheel. W, Brake handle. X, Springs. Y, Tool box, &c. Z, Coal space, &c.

row of rivets. The thickness of the plates is as follows:—Covering plate of fire-box, ⅝ in.; back and throat plates, ⅝ in.; barrel plates,

$\frac{1}{2}$ in.; tube plate, $\frac{3}{4}$ in. The inside fire box has a circular top and is of copper, 4 ft. $5\frac{5}{8}$ in. long by 3 ft. $2\frac{5}{8}$ in. wide at top, and 4 ft. $10\frac{5}{8}$ in. long by 3 ft. $6\frac{5}{8}$ in. wide at bottom. The inside of the top of the fire box is 11 in. above the centre line of the boiler. There is water space of 2 in. all round at the bottom of the box, which is increased at the top of the back plate to 5 in. The tube plate is flanged at the top to 2 in. radius outside, and is $4\frac{1}{4}$ in. broad, and $3\frac{3}{8}$ in. radius outside and $5\frac{13}{16}$ in. broad at the bottom. The tube plate is 3 ft. $8\frac{1}{2}$ in. wide at the top. Back plate flanged at the top to 2 in. radius outside and is $4\frac{1}{4}$ in. broad and $3\frac{3}{8}$ in. radius outside, and $5\frac{13}{16}$ in. broad at bottom. It is dished at fire hole. The crown and sides are in one plate. The sides next to tube plate are made with a pocket equal to the extra width of tube plate at this part, and joined to the plain part of the box with 12 in. radius. Thickness of copper plates: tube plate, $\frac{7}{8}$ in. and $\frac{9}{16}$ in.; back plate, $\frac{9}{16}$ in.; covering plate, $\frac{9}{16}$ in. The fire box is single rivetted, except at the foundation ring, which is double rivetted. Lap of copper plates, $2\frac{1}{4}$ in.; diam. of iron rivets, $\frac{13}{16}$ in., $1\frac{7}{8}$ in. pitch.

The stays are of copper $\frac{7}{8}$ in. diameter, twelve threads per inch; each bar was tested to stand being bent round close, cold, without fracture. The pitch of stays 4 in. The crown of the box is stayed with $1\frac{3}{32}$ in. in copper, and $1\frac{1}{32}$ in. diameter stays in the iron plates, twelve threads per inch, with round collars and square ends screwed in from inside, having nuts on the inside screwed on the top of the copper plate. The ends are rivetted over on outside shell. The copper tube plate is secured to the boiler barrel by eight palm stays.

The foundation ring is made from scrap iron of two bars welded in the centre $3\frac{1}{2}$ in. deep by 2 in. broad, corners $5\frac{3}{8}$ in. radius outside and $3\frac{3}{8}$ in. inside. The bars have projections at each of the corners to allow for the radius outside, so that no V's were required. The boiler contains 220 brass tubes, 10 ft. 8 in. long by $1\frac{3}{4}$ in. external diameter, Nos. 10 and 11 B. W. G., $\frac{3}{4}$ in. water space; expanded at both ends with Dudgeon's patent tube expander; steel ferruled and carefully caulked in the fire box, and projecting $\frac{1}{2}$ in. through the smoke-box tube plate. No ferrules in that end.

The dome is of cast iron $\frac{3}{4}$ in. thick at the top and 1 in. thick at bottom, flattened to $13\frac{3}{4}$ in. diameter on top for receiving the safety-valve seatings. Safety valves and seatings are Ramsbottom's, of the best gun metal. The joints were scraped up perfectly steam-tight and made with boiled oil only.

The chimney is 13 ft. from rails to top, 16 in. diameter at bottom and 17 in. diameter at top inside, made of one plate ¼ in. thick. The base plate is best Yorkshire iron 8 in. high, solid welded, and flanged; secured to the smoke-box by ten ⅝ in. rivets. Plate tube butt-jointed with a 3½ in. strap, 5/16 in. thick on the inside. All the rivets are countersunk and filed flush. The chimney is fitted with a cast-iron top, as illustrated.

The main frames are of Yorkshire iron in one plate from the back buffer beam to the front end of the cylinders, where they are welded. The front part is forged and solidly welded to the frame. They are placed 4 ft. 1½ in. apart from the back end to the front of the cylinders, where they are 3 ft. 11½ in. apart. Their total length is 30 ft. 6 in.; from the inside of the front buffer beam to the centre of the bogie, 5 ft. 4 in.; from the centre of bogie to centre of driving axle, 9 ft. 10 in.; from centre of driving to centre of trailing axle, 8 ft.; from centre of trailing axle to end of frame, 7 ft. 4 in. The height from the rails to the top of the frame is 4 ft.; and the depth of the frame over axle boxes, 18 in. The front buffer beam is 13¾ in. deep and 1¼ in. thick by 7 ft. 2⅝ in. long. It is stiffened with two 2½ in. by 2½ in. by ½ in. angle irons as shown. The back buffer beam is 15 in. by 1¼ in. thick by 7 ft. 2⅝ in., with a slot cut for draw bar.

The horn blocks are of the best tough cast iron free from defects, the sliding surfaces, which are to be 5¼ in. wide, are continued across the top, and the flange with which the same is fixed to the frame is continued round in a similar manner.

The driving and trailing axle boxes are crucible cast steel, 2 in. thick at the crown, 1⅝ in. and 1½ in. thick at sides, 7⅛ in. wide, a flange 15/16 in. thick by 1 ft. running down the sides. The bushes also recessed at the top for white metal. A gun-metal keep is placed below the axle.

The driving springs are volutes, 7 in. diameter by 8¾ in. long. The trailing springs are composed of one plate 5 in. broad by ½ in. thick, and seventeen plates 5 in. broad by ⅜ in. thick, and one wrought-iron packing piece 5 in. broad by ½ in. thick, 3 ft. 6 in. span and 3½ in. camber when loaded.

The driving, trailing, and bogie axles are of the best Yorkshire iron, double faggotted. The wheels are solid forged, the coupled wheels having forged balance weights and crank bases. The tyres are solid rolled crucible cast steel, 3 in. thick on tread by 5½ in.

wide, and secured on the inside by Drummond's patent clip ring tyre fastening. The cylinders are 17 in. diameter and 26 in. stroke, 2 ft. 3 in. centres; the back ends are cast solid. They are lagged with wood and covered with sheet iron. The thickness of metal in the cylinder barrel is 1 in.; in the steam chest, ½ in.; the steam ports are 1⅜ in. by 14½ in.; the exhaust port 2¾ in. by 14½ in.; bridges, 1⅛ in.; width over faces, 10¾ in. The cylinders have an inclination 1 in 34. The slide valves are made of gun metal; they have an outside lap of 1 in., a travel of $4\frac{3}{16}$ in., and a lead of ⅛ in. The buckle is of wrought iron, solid with spindle. The pistons are of gun metal 4 in. deep, with two cast-iron rings ¾ in. wide by $\frac{7}{16}$ in. thick. The piston rods and crossheads are forged solid of selected Yorkshire iron. The slide blocks are of cast iron of the same quality as the cylinders, 12 in. long by 3¼ in. wide, forced on the gudgeon pins with a pressure of 4 tons, and accurately fitted to the slide bars. The connecting rods are forged in one piece, without weld, from the best selected scrap iron; section at large end, 5 in. by 2 in.; at small end, 3½ in. by 2 in.; and 6 ft. 6 in. centre to centre. The outside rods are made of the very best selected scrap iron forged in one piece without weld, and fitted with gun-metal bushes. Bushes are pressed into the rod ends, secured in their places with taper pins and set screws. The intermediate valve spindles are made of the best selected Yorkshire scrap iron 3½ in. diameter. The bushes are gun metal.

The reversing gear is of the screw type with cast-iron column and wheel, worked by a bell crank and rod. The eccentric rods are made from the best selected scrap iron, having a foot forged on for bolting to the straps. The straps are of cast iron and fitted together without liners. The two eccentrics of each side are cast together in halves, the outside eccentrics are bored, recessed, and tapped to receive the screw, securing it together. The inside has a round flange which abuts against a similar flange on the opposite eccentrics; both flanges are tightly embraced with a wrought-iron hoop, bolted together with two 1 in. diameter bolts. A projecting lug is cast on the outside eccentric, and carefully fitted to the web of the crank for driving the eccentrics. The throw of the eccentrics is 6½ in.; they are 2⅝ in. wide.

The boiler is fed by two injectors, No. 8, with movable cones. A tank is provided on each side of the engine to carry 950 gallons of water. The iron plates are $\frac{3}{16}$ in., excepting the flanged plates for the splasher's sides, which are of Yorkshire iron ¼ in. thick. The angle irons are 1¾ in. by 1¾ in. by $\frac{5}{16}$ in.; rivets ½ in. diameter and 1½ in. pitch in bottom. A cast-iron dry sand box is placed on each side of smoke box. The injector pipes are of copper solid drawn. Delivery pipe, 1½ in. external diameter, by No. 10 B. W. G.; feed pipes, 1¾ in. external diameter, by No. 10 B. W. G.; steam pipe, 1¼ in. external diameter, by No. 10 B. W. G. All flanges have been scraped up to a true surface so as to make a perfectly steam-tight joint, with boiled oil only.

The engine is fitted with the Westinghouse automatic air brake on the driving and trailing wheels.

The bogie frames are Yorkshire iron, 1 in. thick by 8 ft. 9⅞ in. long. A cast-iron frame is fitted between the frames, with a moving frame supported by two volute springs at the ends. The bogie centre is rivetted on to a 1⅛ in. thick transverse plate, which is rivetted to the main frames with 4 in. by 4 in. by ¾ in. angle irons. The centre pin is 2½ in. diameter, fitted with a wrought-iron washer and cotter underneath. The centre on the moving frame is arranged for and fitted with oil cups for lubricating the moving surfaces. The cast-iron frame is rivetted to the plate frame as shown; frames 2 ft. 8¼ in. apart, and wheel centres, 6 ft. 6 in.

The springs are composed of twelve steel plates, 5 in. broad by ½ in. thick, and one wrought-iron packing piece, ½ in. thick, 4 ft. centres, 2½ in. camber loaded.

The boiler was tested previous to being put in the frames by hot water to a pressure of 200 lbs. per square inch, by the hydraulic pump; and with steam to 150 lbs. per square inch.

PASSENGER ENGINES FOR GREAT SOUTHERN AND WESTERN RAILWAY OF IRELAND.

The frames are inside, of solid plate, 1 inch thick. They are attached at one end to the cylinders, and at the other end to a cast-iron foot plate, and are stayed by the motion plate and by a plate in front of the fire box. The boiler is of ½-inch Lowmoor plate, 4 feet inside diameter. Each ring of the boiler is formed of a single plate; and the two sides and top of the outside fire-box casing are also formed of a single plate. The fire box is of ½-inch copper, the tube plate being ¾ inch thick, and the two sides and crown are formed of a single plate. There are 185 tubes of brass. The cylinders are inside, and 17 inches in diameter, the length of stroke being 22 inches. The driving wheels are 6 feet 6 inches in diameter, and are coupled to the trailing wheels. The valve motion is of the ordinary kind, a screw being used for reversing. The coupling rods have cast-iron bushes, lined with white metal. The axle boxes are of cast iron, and have the brasses cast into them. The horn blocks of cast steel are attached to the frame all round the opening for the axle box; they have adjustable wedges for taking up the wear of the axle boxes. The slide blocks are of cast iron, and the little end steps are of wrought iron, case-hardened. The boiler is attached to the frames at the smoke-box end, is free to expand at the fire-box end, and does not touch the motion plate. The heating surface consists of: tubes, 835 superficial feet; fire box 96, and fire grate 17½ superficial feet. The wheel base is from the driving to the leading wheels 7 feet, and from the driving to the trailing wheels 7 feet 9 inches. The weight on the leading wheels is 10 tons, on the driving wheels it is 10·8 tons, and on the trailing wheels it is 9·5 tons, the total weight being thus 30·3 tons.

The performance of these engines is shown in the following table:—

Length of Journey.	Speed per Hour.	Average Load of Six-wheel Carriages.	Maximum Load for Average of whole Journey.	Maximum Load for part of Journey.	Average Consumption of Coal per Engine Mile, 252,554 Miles.
Miles.	Miles.	Carriages.	Carriages.	Carriages.	lbs.
165½	38	8·03	11·54	14	25·64
,,	38	7·64	10·54	13	
,,	30	8·56	14·67	21	
,,	30	8·59	14·47	16	

AVERAGE WEIGHT OF CARRIAGES.

	Tons.	cwts.		Tons.	cwts.
First class, ...	10	3	Composite, ...	8	10
Second class, ...	9	8	Post-office vans,... ...	10	0
Third class, ...	9	10	Guards' vans, ...	9	12

The coal was from South Wales, of good quality, though much of it was small, being broken in shipment.

These engines have run an average distance of 48,748 miles in each interval between general repairs. The cost for repairs, exclusive of shop expenses and tools, has been a trifle under 1*d.* per mile.

The light passenger engines are of similar construction; the chief dimensions are:—Diameter of cylinders, 16 inches: length of stroke, 20 inches; diameter of the driving wheels, 5 feet 8 inches; the wheel base is, from the driving to the leading wheels 6 feet, and from the driving to the trailing wheels 7 feet 11 inches. The weight on the leading wheels is 9·2 tons, on the driving wheels it is 9·2 tons, and on the trailing wheels it is 8·8 tons, the total weight being thus 27·2 tons. The heating surface consists of: tubes, 774 superficial feet; fire box 88½, and fire grate 16 superficial feet. There are 175 tubes.

The performance of these engines is shown in the following table:—

Length of Journey.	Speed per Hour.	Average Load of Six-wheel Carriages.	Maximum Load for Average of whole Journey.	Maximum Load for part of Journey.	Average Consumption of Coal per Engine Mile, 644,412 Miles.
Miles.	Miles.	Carriages.	Carriages.	Carriages.	lbs.
165½	32	6·17	9·64	10	23·36
,,	30½	6·82	11·42	13	
,,	30½	4·93	7·64	10	
,,	32½	5·65	12·00	12	
,,	26½	7·00	11·55	18	
,,	28½	7·68	16·66	25	
,,	28¾	7·17	15·00	15	
,,	28	7·18	14·58	15	

These engines have run an average distance of 54,635 miles in each interval between general repair. The cost of repairs, exclusive of shop expenses and tools, has averaged four-fifths of 1*d.* per mile.

GOODS ENGINE FOR GREAT SOUTHERN AND WESTERN RAILWAY OF IRELAND.

In Fig. 542 is shown an example of a locomotive specially adapted for goods traffic. It is a six-wheeled coupled goods engine made for the Great Southern and Western Railway of Ireland, and is believed to be one of the most powerful goods engines in use upon an Irish railway.

There are no frames outside the wheels. The two inside frames extend the whole length of the engine, and are of solid plate, 1 inch thick, connected in front by the buffer beam and cylinders, under the boiler barrel by the motion bracket in front of the fire box, by a strong ⅞-inch angled plate, and by a heavy cast-iron block fixed firmly between the frames, forming the base for the foot plate. The train is drawn from this cast-iron block, and the boiler is free to expand along the frames. The horn blocks are of cast steel, and extend on both sides of, and over, the top of the openings for the axle boxes. The axle boxes are of cast iron with brass bearings, and they are adjustable by wedge pieces recessed into the horn blocks so as to take up the wear; these are held up by screws inserted from the back. The boiler is of Yorkshire plates, ½ inch thick as a rule, but ¾ inch where the tubes are fixed. The fire box is of copper, of the ordinary square form, ½ inch thick, swelled to ¾ inch where the tubes are fixed, and connected to the outside shell in the ordinary way.

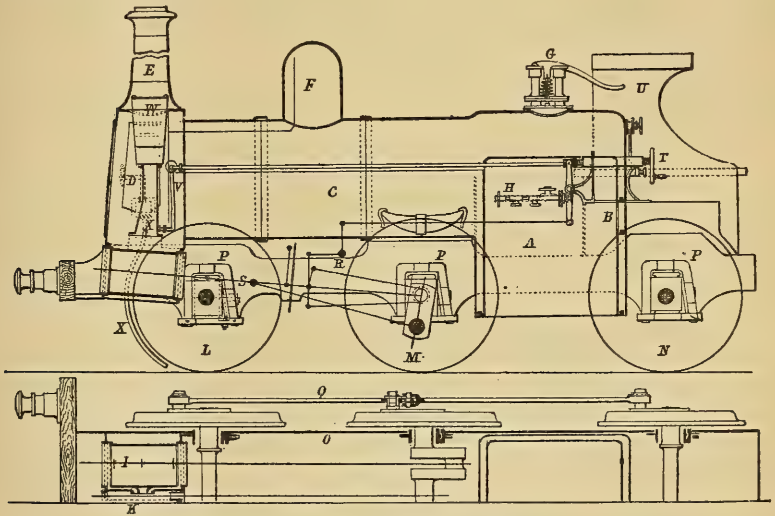


Fig. 542.—Great Southern and Western Railway of Ireland Goods Engine.

A, Fire box. B, Fire door. C, Body of boiler. D, Smoke box. E, Chimney. F, Steam chest. G, Safety valve. H, Injector. I, Cylinder. K, Valve chest. L, Leading wheel. M, Driving wheel. N, Trailing wheel. O, Frame. P P, Wedges for axle boxes. Q, Outside connecting rods. R, Weigh shaft. S, Line of valve spindle. T, Reversing wheel and screw. U, Cab. V, Steam pipe for counter-pressure brake system. W, Spark trap. X, Blast pipe.

The boiler is fed by two injectors, placed horizontally on each side of the fire box. Some boilers now being made have vertical injectors feeding through the back of the fire box into the front, thus avoiding all outside pipes, as described in the London and North-Western Railway passenger engine. The tubes are of brass, 160 in number, and each 2 inches external diameter. The safety valves are arranged to prevent weighting by the driver. A spark arrester of wire, of the inverted truncated form, is placed in the chimney. The cylinders are 17 inches diameter, with a stroke of 24 inches; the slide valves working vertically between them. The valve motion is of the usual form, the link being shifted by a screw motion, so as to insure absolute control by the driver. All the wheels are coupled, and have a diameter of 5 feet 1¼ inch. The tyres and the axles are of cast steel. The coupling-rod ends are furnished with cast-iron bushes, lined with white metal. The small ends of the connecting rods have wrought-iron steps, case-hardened. The sand boxes are fixed in the smoke box to insure the dryness of the sand. The counter-pressure steam brake is applied, in order to obtain a greater degree of safety in descending inclines, and to enable the driver to assist in stopping the train.

The heating surface of this engine is:—

In the tubes, ...	846	sq. feet.
,, fire box, ...	93	,,
Total, ...	939	sq. feet.

The fire-grate area is about 17·5 square feet

The weight upon the wheels, when the engine is in working order, is:—

	Tons.	cwts.	qrs.
On the leading wheels, ...	10	12	1
,, driving wheels, ...	11	6	3
,, trailing wheels, ...	8	15	2
Total, ...	30	14	2

The total wheel base is 15 feet 6 inches.

The engine will draw a weight of 607 tons on a level at a speed of 25 miles an hour, with a working pressure of 140 lbs. Its average consumption of coal is 35 lbs. per mile with a load of fifty-five waggons.

The performance of these engines is shown in the following table:—

Length of Journey.	Time occupied in Running.		Time occupied at Stations.		Speed per Hour.	Average Load for whole Journey.	Maximum Load.	Average Consumption of Coal per Engine Mile, 1,028,826 Miles.
Miles.	Hours.	mins.	Hours.	mins.	Miles.	Waggons.	Waggons.	lbs.
165½	9	22	3	26	17¾	31·5	50	37·6
107	5	50	2	16	18¼	32·3	50	
107	5	40	3	46	19	24·8	51	
96½	5	25	3	52	17¾	29·9	49	
165½	8	37	3	8	19¼	27·7	52	
107	5	40	4	56	19	30·8	54	
107	5	36	1	45	19	30·7	52	
96½	5	29	3	30	17½	27·5	52	

The waggons, which are nearly all covered, weigh from 4¾ to

5½ tons, and carry 6 tons. The probable average load is from 3 to 4 tons.

These engines have run an average distance of 44,232 miles in each interval between general repair. The cost for repairs, exclusive of shop expenses and tools, has been 0·9*d.* per mile.

GOODS ENGINE—BOMBAY, BARODA, & CENTRAL INDIA RAILWAY.

This engine has been specially designed for the working of heavy traffic in India, where the gauge, 5 feet 6 inches, has given great facility for the construction of a powerful engine on a reasonable length of wheel base. It will be found that several appliances exist for suiting this engine to the requirements of a colonial railway, and in this respect it differs from ordinary goods engines in this country. The frames consist of a pair of longitudinal plates, 1⅛ inch thick, placed inside the wheels, connected at various intervals by the buffer beam, the cylinders, the motion plate, a strong cross bracket in front of the fire box, a similar one behind it, and by strong plates and angle irons at the foot-plate end. The train is drawn by a pin inserted through these plates, and, as the boiler has no positive attachment to the frames behind the smoke-box tube plate, it is free from all strain arising from the haulage of the train.

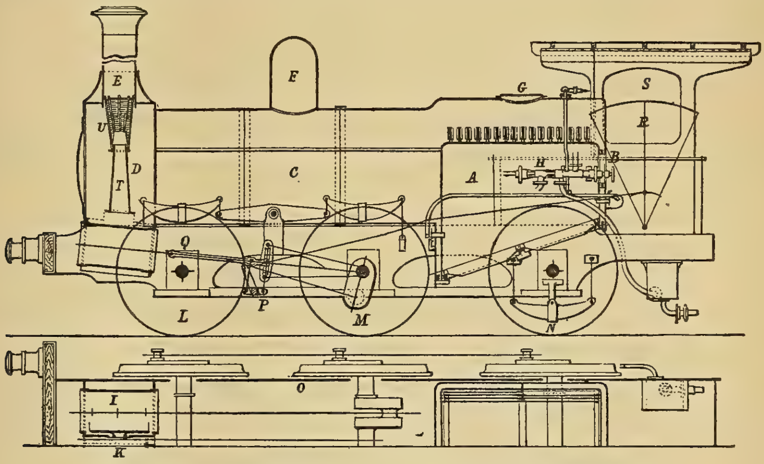


Fig. 543.—Bombay, Baroda, and Central India Railway Goods Engine.

A, Fire box. B, Fire door. C, Body of boiler. D, Smoke box. E, Chimney. F, Steam chest. G, Manhole door. H, Injector. I, Cylinder. K, Steam chest. L, Leading wheel. M, Driving wheel. N, Trailing wheel. O, Frame. P, Weigh shaft. Q, Line of valve spindle. R, Reversing lever. S, Cab. T, Blast pipe. U, Spark trap.

The boiler is of the ordinary form, 4 feet 4 inches diameter, and 10 feet 9 inches long, of Yorkshire plates, ½ inch thick. The firebox shell is of the same material and thickness, deep in front, but sloping backwards, with a long inclined fire grate suitable for burning the small and inferior coal usually procurable in India. The fire box proper is of copper, of the same tapering form as the external shell, all the plates being ½ inch thick, but the tube plate is swelled to ⅞ inch where bored to receive the tubes. The wrought-iron roof girders in this engine run transversely, so as to obviate the necessity for their being so deep as would have been requisite had they been placed longitudinally. A spark arrester of wire is fixed on the top of the blast pipe, and extends into the chimney.

The water is supplied to the boiler by two injectors, either of which is capable of delivering the amount of water usually evaporated. The tubes are of brass, 222 in number, and each 2 inches external diameter. The cylinders are 18 inches diameter, with a stroke of 24 inches; the slide valves being placed vertically between them. The valve motion is of the straight-link double-lever form. All the wheels are coupled, and are 5 feet diameter on the tread. There is a cab with a double roof of wood and of iron over the foot plate to shelter the driver from the rain and the great heat. A cow catcher is fixed in front of the buffer beam to fit the engine for use on the unfenced railways of India.

The escape of smoke, when the engine is standing still, is prevented by the introduction of air above the surface of the fire by means of jets of steam through hollow stay tubes at the front and back of the fire box.

The heating surface of this engine is:—

In the tubes, ...	1278·0	sq. feet.
,, fire box, ...	99·3	,,
Total, ...	1377·3	sq. feet.

The fire-grate area is about 25·5 square feet.

The engine will draw a weight of 694 tons on a level at a speed of 25 miles per hour, with a working pressure of 140 lbs. Its consumption of coal is 59·25 lbs. per mile for an average load of 490 tons. The cost of repairs has been 2·15 annas, or, say, 3·22*d.* per mile.

A peculiar feature of this engine is the position of the hind axle under the fire box, permitted by the long sloping fire grate, and by the shallowness of the end of the fire box. This arrangement answers the double purpose of allowing a comparatively short wheel base and an equable distribution of the weight of the engine upon the wheels, 11 tons, 11 tons 16 cwts., and 11 tons 16 cwts., being carried on the leading, the driving, and the trailing wheels respectively. As there is less weight on the leading wheels than on either of the other pairs, it might be supposed that there would be danger of the engine running off the line under certain circumstances; but this is not the case, as the weight actually upon the springs of the leading wheels is greater than on those of the driving wheels.

FURNESS RAILWAY TANK ENGINE.

This locomotive was constructed for the conveyance of mineral or heavy goods traffic over a portion of the Furness railways, having gradients of 1 in 100, and 1 in 80, &c., for 11 miles. It was desired to get as powerful an engine as possible on six wheels, with inside cylinders, and to carry fuel and water sufficient for a considerable distance, in case it was found necessary to take the train forward on the main line. The cylinders are between the two frames, which extend the whole length of the engine, and are 1¼ inch thick.

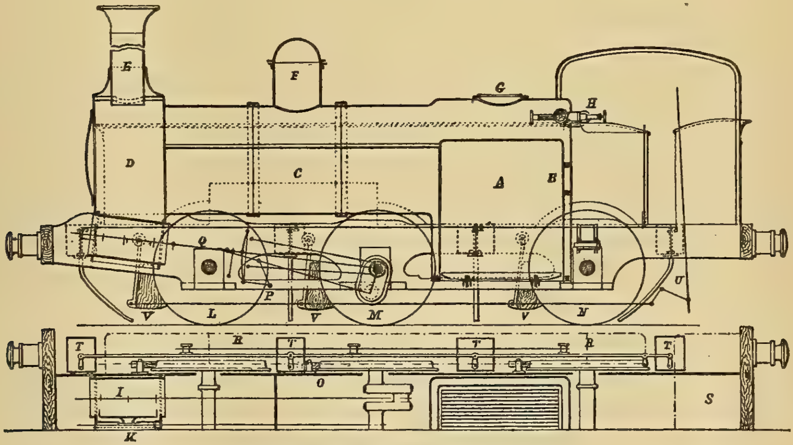


Fig. 544.—Furness Railway Tank Engine.

A, Fire box. B, Fire door. C, Body of boiler. D, Smoke box. E, Chimney. F, Steam chest. G, Manhole door. H, Injector. I, Cylinder. K, Valve casing. L, Leading wheel. M, Driving wheel. N, Trailing wheel. O, Frame. P, Weigh shaft. Q, Line of valve spindle. R R, Water tank. S, Coal box. T T, Sand boxes. U, Brake gear. V V, Brake blocks.

Besides being connected by the cylinders, the frames are tied by two cross brackets under the boiler, by the buffer plank in front of the cylinders, and by four cross ties behind the fire box; the frames are further strengthened externally by heavy angle irons arranged for carrying the water tanks. The train is drawn from the foot plate, and as the boiler is free to slide in the frames, all haulage strain is removed from it, as well as that arising from a too unyielding connection with the frames. The horn blocks are of cast iron. Those of the driving and the front axles are carried round the top of the horn plate to strengthen the frames. The boiler is of Yorkshire plates, ½ inch thick as a rule, but ¾ inch thick where the tubes are fixed. The fire box is of copper, $\frac{9}{16}$ inch thick, of the ordinary square form, connected with the outside shell by a square wrought-iron frame at the bottom, and by copper screw stays at the sides, front and back. The roof is stayed by longitudinal wrought-iron girders, connected by means of sling stays, with T irons rivetted to the roof of the external casing. The proper combustion of the fuel is effected by the admission of air through the fire door, deflected on to the surface of the fire by the ordinary scoop, aided by a fire-brick arch, placed across the fire box under the tubes, which serves also to prevent the emission of sparks through the tubes and chimney. The fire bars are simple flat pieces of iron, with two corners cut off, and are supported by two cross bars, with pins to keep the distances equal. The boiler is fed by two injectors, and the engine can therefore stand any required time, when waiting as a pilot, without being set in motion to obtain water for the boiler. The tubes are of brass, 186 in number, and each 2 inches external diameter. The cylinders are 18 inches diameter, with a stroke of 24 inches, and the valves work vertically between them. The valve gearing is of the ordinary shifting-link class, and is reversed by the common lever handle. All the wheels are coupled, and have a diameter of 4 feet 6½ inches. The end of the engine is carried by a transverse elliptical spring. A coal bunker and cab are conveniently placed on the foot plate. The arms of the crank axle, which is of Bessemer steel, are hooped, to prevent accident in case of fracture.

As the engine is intended to work in either direction, the cab is arranged as a screen both forward and backward.

Tanks to contain 1000 gallons of water are placed along each side of the smoke box, the boiler, and the fire box above the level of the frame. The coal is carried behind the engineman's platform in bunkers, which hold 2 tons. A powerful screw break is attached to the engine, actuating six blocks in front of each of the six wheels. Sand boxes supply sand in front of, or behind each wheel, as required, and are so contrived as to be opened or closed by one set of levers for each direction of the engine.

The heating surface in this engine is:—

In the tubes, ...	1047·8	sq. feet.
„ fire box, ...	96·2	„
Total, ...	1144·0	sq. feet.

The fire-grate area is nearly 15 square feet.

The weight upon the wheels, when the engine is in working order and the tanks full, is:—

	Tons.	cwts.
On the leading wheels, ...	13	16
„ driving wheels, ...	14	11
„ trailing wheels, ...	13	8
Total, ...	41	15

The total wheel base is 15 feet.

The engine will draw a weight of 872 tons on a level at a speed of 20 miles per hour, and a weight of 367 tons up an incline of 1 in 80 at a speed of 11¾ miles per hour, with a working pressure of 145 lbs. to the square inch. Its consumption of fuel with this latter load has been 40·16 lbs. per mile, taking the whole trip, which includes the descent as well as the ascent of the gradients before alluded to. The cost of repairs has not been taken into account, as the distance run does not usually exceed 76 miles per day.

This engine was designed to obtain as much power as was possible upon six wheels. The frames have been put inside the wheels, to allow convenient access to the motive parts; the cylinders being placed inside, to secure great structural stability. The tanks are arranged alongside the boiler to distribute equal weights upon the wheels, whether the tanks are full or empty. The distribution of the weight, when they are empty, is:—

	Tons.	cwts.	qrs.
On the leading wheels, ...	11	7	2
„ driving wheels, ...	11	16	2
„ trailing wheels, ...	10	8	2

It is believed that the engine has in all respects answered the purpose for which it was built.

For engines with rigid frames, a simple and convenient arrangement has been applied, in the shape of a sliding top to the leading, and sometimes to the trailing axle boxes. This cap has a double incline in the transverse direction of the engine. The axle box has also similar corresponding inclines, so that when passing round a curve the leading wheels are free to move sideways, without at once carrying the engine with them. As the axle box incline must at the same time lift the engine when so sliding, the gravity of the engine tends to make it assume its normal position on the axle boxes as soon as the road permits this to be done.

NARROW-GAUGE ENGINES FOR STEEP INCLINES.

To enable engines to draw heavy loads up excessively steep inclines a system invented by Mr. Fell has been adopted, in which a set of horizontal wheels are pressed against a central rail, giving in this manner additional traction hold. A railway on this system was worked successfully over Mont Cenis during the construction of the tunnel through that mountain.

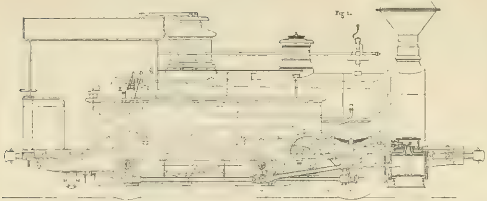
The Festiniog Railway in North Wales is the smallest gauge line in Great Britain used for passenger traffic. The gauge is only 2 feet, with correspondingly small and light rails and roadway generally. Some of the curves are as low as 2 chains radius. The steepest gradients are 1 in 60 and 1 in 80.

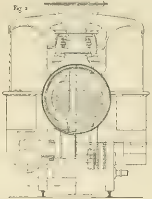
The carriages are peculiarly constructed, to suit so narrow a gauge. They are 10 feet in length, and fully 6 feet in breadth and height, with four wheels 18 in. diameter. The seats are arranged so that the passengers are seated along the central part of the carriage, back to back. The engines weigh about 7½ tons, with four coupled wheels each 2 feet diameter, the cylinders being 8 inch diameter with a 12-inch stroke.

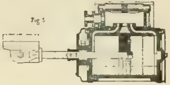
The small railway line on the Righi Mountain in Switzerland has a gauge of 1 metre, and as the gradients are excessively steep, in some cases as much as 1 in 4, it is necessary to provide for greater grip of the locomotive than can be obtained by weight on smooth wheels only. This is accomplished by placing a central toothed rail or "rack" between the bearing rails, and by means of suitable gearing sufficient "bite" is obtained. The engine, which has a vertical boiler, draws only one carriage. The radii of the curves are 180 metres.

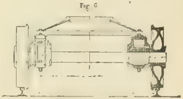
The Vesuvius Railway leads from the foot of the cone to the

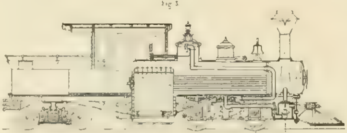
NARROW-GAUGE LOCOMOTIVES.

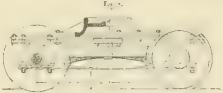


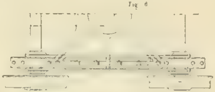












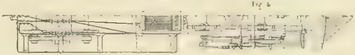


Fig 1 Elevation of Danforth Locomotive Tender

Fig 2 Transverse Sections of Danforth Locomotive Tender

Fig 3 Elevation of Locomotive Tender with Mason double truck.

Fig 4 Half Plan of Locomotive with double truck.

Fig 5 Longitudinal section of a Cylinder

Fig 6. Truck of a Passenger Locomotive on the Louisville and Nashville R. R. Front view and transverse section.

Fig 7 Longitudinal section and side view of Truck of Passenger Locomotive Louisville and Nashville R. R.

Fig 8. Half Plan of the preceding

summit, and has a double line of rails with fixed engines which wind the carriages up and down by means of steel wire ropes. The inclination is very steep, sometimes about 40°, and the carriages are so arranged that the seats are kept horizontal, and the wheels are arranged to grip the rails in such a manner as to prevent their leaving the rails, and powerful automatic brakes are fitted to prevent accident in the case of a rope breaking.

A light system of railroad has been introduced into Canada, the gauge being 3 feet 6 inches. The gradients are steep and the curves sharp. The permanent way has timber sleepers, and the rails are flat-bottomed, weighing 56 lbs. per yard, being fastened to the sleepers with dog spikes. The engines are coupled in eight wheels, and weigh 30 tons, taking a load of 360 tons up a gradient of 1 in 60. Curves are used in some places of 500 feet radius on gradients of 1 in 60 and 1 in 70. In one case a gradient of 1 in 50 extends for four miles.

ENGINES FOR NARROW-GAUGE MINERAL LINES HAVING STEEP GRADIENTS.

The lines leading from the numerous mines and works in our mineral and manufacturing districts to the main lines of railway were formerly merely tramways worked by horses, but the need for more ready and cheaper communication soon led to the introduction of a special class of locomotive engine fitted for such work.

The following are the details of tank engines employed on one of these branch lines about 2 miles in length, connecting the lime quarries with the main line of railway. The quarries are situated at a height of nearly 1000 feet above the sea; the country is very bleak, and much exposed to snow and rain storms in winter. Starting from the lowest level the line runs 1400 yards 1 in 80, 360 yards 1 in 12, 450 yards 1 in 15, 630 yards 1 in 18, 680 yards 1 in 15. The gauge of the rails is 32 inches; the rails, 28 lbs. per yard. This single line was originally indifferently constructed, and crosses a deep ravine on a narrow embankment about 150 yards in length, before commencing the steep ascent of 1 in 12, with curves of one and a half chains in some but not dangerous parts of the line. The first experimental engine on this line was designed and constructed by Messrs. Hawthorn & Co. of Leith, the usual formula being adopted, and which has been found to be quite correct in practice.

The cylinders were 8 inches in diameter, with a piston stroke of 15 inches. Steam pressure, 120 lbs. in the boiler. There were four wheels coupled, 27 inches diameter, with a wheel base of 4½ feet. The engine in working trim weighed 7 tons 5 cwts. This locomotive, when put to work, was found to take up the gradient of 1 in 12 about its own weight, besides itself, at 4 to 6 miles per hour in any state of the rails, sand being used when necessary, and it could be started or stopped with the load on the incline, the brake power having ample control over the motion of the train. Taking the foregoing result by calculation from the formula $\frac{d2lp}{D}$, with four-fifths of the boiler pressure for average pressure in cylinders, or 96 lbs. against 120 lbs., the engine should take about 7½ tons gross load, besides its own weight, allowing 22·4 lbs. per ton friction for load, and limiting the possible adhesive force to one-fifth of engine weight on incline. The average cost of maintenance for this engine amounted to 12*s.* per day.

Another engine constructed for this narrow-gauge line had cylinders 10 inches diameter, stroke of piston 15 inches, with 150 lbs. steam-boiler pressure; wheels 27 inches in diameter, coupled 5 feet apart, or wheel base. The weight in working trim being 11 tons 11½ cwts., it was found on trial to take over the 1 in 12 gradient a load of 18 tons, composed of empty trucks, with 125 lbs. per square inch in boiler, and holding this pressure well at the summit of the incline. With 150 lbs. steam pressure in the boiler it is calculated to take a load of 20 tons, with a margin of one-fifth more, as a possible result in favourable circumstances.

A line of railway in Portugal, which had been formerly worked with about seventy mules, with drivers, &c., at a considerable cost, may be taken as a favourable example of what we may term narrow-gauge lines with small-wheeled mountain locomotive engines. The railway runs a distance of 11 miles over a very rugged country, crossing many ravines and torrents, and with many curves, some as sharp as 1½ to 2 chains radius. The gradients, starting from the sea level to the mines which supply copper ore, are as follows:—(1) Rising 1 in 23 to 1 in 1000, 3¼ miles; (2) falling 1 in 24 to 1 in 60, 2 miles; (3) rising 1 in 30 to 1 in 190, 2 miles; (4) falling 1 in 50 to 1 in 19, 1½ mile; (5) rising 1 in 1500 to 1 in 43, 3 miles. The gauge is 3½ feet; rails, 35 lbs. per yard.

The first engine employed had 9-inch cylinders, with a piston stroke of 15 inches; steam pressure in boiler, 130 lbs.; the wheels being 27 inches diameter. This engine hauled 20 tons, waggon and ore, up the incline of 1 in 19, and could have done a great deal more (waggons, say 22 cwts. each, carrying 2 tons of ore); also thirty waggons and forty men over the 1 in 30=36 tons, in splendid style; engine in trim weighing 10·5 tons. The calculation, as before, meets this load on the 1 in 19 gradient exactly, namely, 20 tons, and on 1 in 30 gives 38 tons. It was found from experiments made with such engines that this limit may be practically increased one-fifth, thus leaving a large margin for effect.

Small engines coupled together.—Whilst the experiments were going on in Derbyshire for the proposed Mont Cenis Railway, the question was discussed whether the central-rail system possessed any advantage over ordinary locomotives and railway lines, likely to recommend its adoption unless in very exceptional circumstances. One point raised was, whether two engines coupled together could not be used with as much or more advantage than a single engine of twice the weight.

An experiment was therefore made with two of these small engines; the front engine having an 8-inch cylinder, 15-inch stroke of piston, 27-inch wheels, and 120 lbs. steam; and the second one, 9-inch cylinder, 15-inch stroke of piston, 27-inch wheels, and 150 lbs. steam. These coupled together took over an incline of 1 in 12 twenty empty trucks=24 tons weight, at 4 to 6 miles per hour; and the latter by itself, with 125 lbs. steam pressure in the boiler, took 14 tons 12 cwts. over the same gradient, the weight of engine in working trim being 10 tons. Calculating as before on one-fifth weight of engine on gradient for adhesion, one-fifth less average pressure in cylinder than that in boiler, and making extra allowance for friction of load, owing to number and inferior construction of trucks and railway, the load to be taken would be about 20 tons. Engines coupled together are often used when the train of carriages is heavy. It does not appear that any loss accrues from using the engines together, but rather the reverse; probably any disadvantage from want of simultaneous action of wheel trod on the rails is counterbalanced by the points of adhesion gained. There can therefore be little doubt of the comparative advantage of small engines coupled together when required on such railways as have been under consideration, as arrangements can always be made to utilize them, when not in use for through haulage, for shunting, and other purposes.

In these engines the frame plates are connected together by one or more water tanks, of which they form the sides, the whole being framed on angle iron, with all joints rivetted and caulked in the same manner as the boiler. By this arrangement, the tanks being an integral part of the framing, great rigidity is secured to the latter, while the weight of water, &c., is carried at the lowest possible level, insuring steadiness to the engine in running. The working gear, being entirely outside of the frames, can be examined or repaired with facility, and without the necessity of using a pit to get access to any part. The principle is applicable to locomotives variously constructed as regards number and position of wheels, &c.

DIMENSIONS OF SMALL TANK NARROW-GAUGE ENGINES.

Diameter of Cylinder.	Stroke.	Diameter of Wheels.	Centres of Wheels.	Steam Pressure in Boiler.	Weight in tons.
8 inches.	15 inches.	27 inches.	4½ feet.	120 lbs.	7 tons 5 cwts.
9 ,,	15 ,,	27 ,,	4½ ,,	150 ,,	10 ,, 0 ,,
10 ,,	15 ,,	27 ,,	5 ,,	125 ,,	11 ,, 11½ ,,
9 ,,	15 ,,	27 ,,	5 ,,	130 ,,	10 ,, 10 ,,
10 ,,	15 ,,	27 ,,	5 ,,	...	...
12 ,,	18 ,,	30 ,,	5 ,, 6 in.	...	...

In Figs. 545 and 546 we give examples and details of a four-wheeled and a six-wheeled tank engine, both having the tank placed underneath the boiler. The dimensions of the first engine are as follows:—Diameter of cylinders, 11 inches; length of piston stroke, 18 inches; diameter of driving wheels, 3 feet; distance between centres of wheels, 6 feet; diameter of body of boiler, 3 feet; length of body, 8 feet 3 inches; 81 brass tubes, 2 inches diameter outside; heating surface in fire box, 38 square feet; tube surface, 352 square feet. The dimensions of the second engine are:—Diameter of cylinders, 15 inches; length of piston stroke, 21 inches; diameter of wheels, 3 feet 6 inches; 5 feet 9 inches, centres; 11 feet 6 inches, wheel base; diameter of body of boiler, 3 feet 9 inches; length of body, 9 feet; 100 brass tubes, 2¼ inches diameter outside; heating surface in fire box, 67 square feet; tube surface, 545 square feet; contents of tanks, 800 gallons; for 4 feet 8½ inches gauge of rails; weight of engine in working trim, 28 tons.

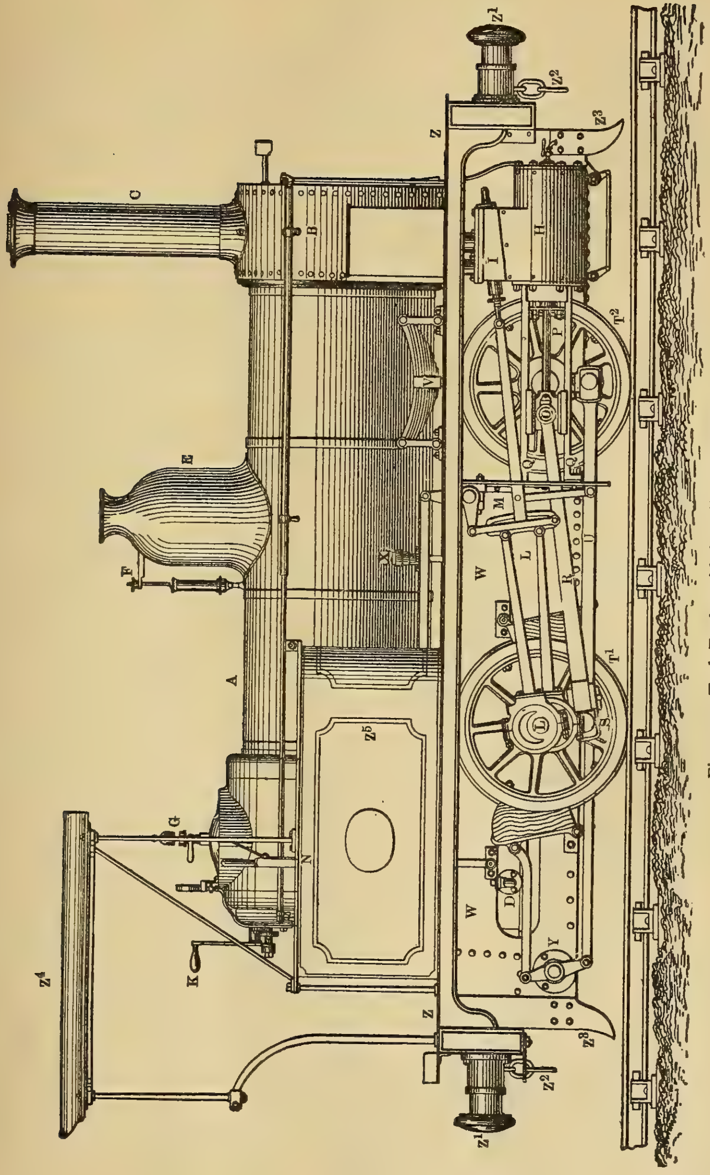


Fig. 545.—Tank Engine with Four Wheels coupled.

A, Boiler. B, Smoke box. C, Chimney. D, Blow-off tap. E, Steam dome. F, Safety valve. G, Steam whistle. H, Cylinder. I, Valve casing. K, Regulator handle. L, Eccentrics and link motion. M, Weigh shaft. N, Starting handle. O, Crosshead. P, Piston rod. Q Q, Guide bars. R, Connecting rod. S, Crank pin. T^1 T^2, Driving and leading wheels. U, Side rod. V, Spring. W, Framing and tank. X, Check valve. Y, Brake gear. Z, Platform. Z^1 Z^2 Z^3 Z^4, Buffers and end beams, safety chains, rail guards, awning. Z^5, Coal box.

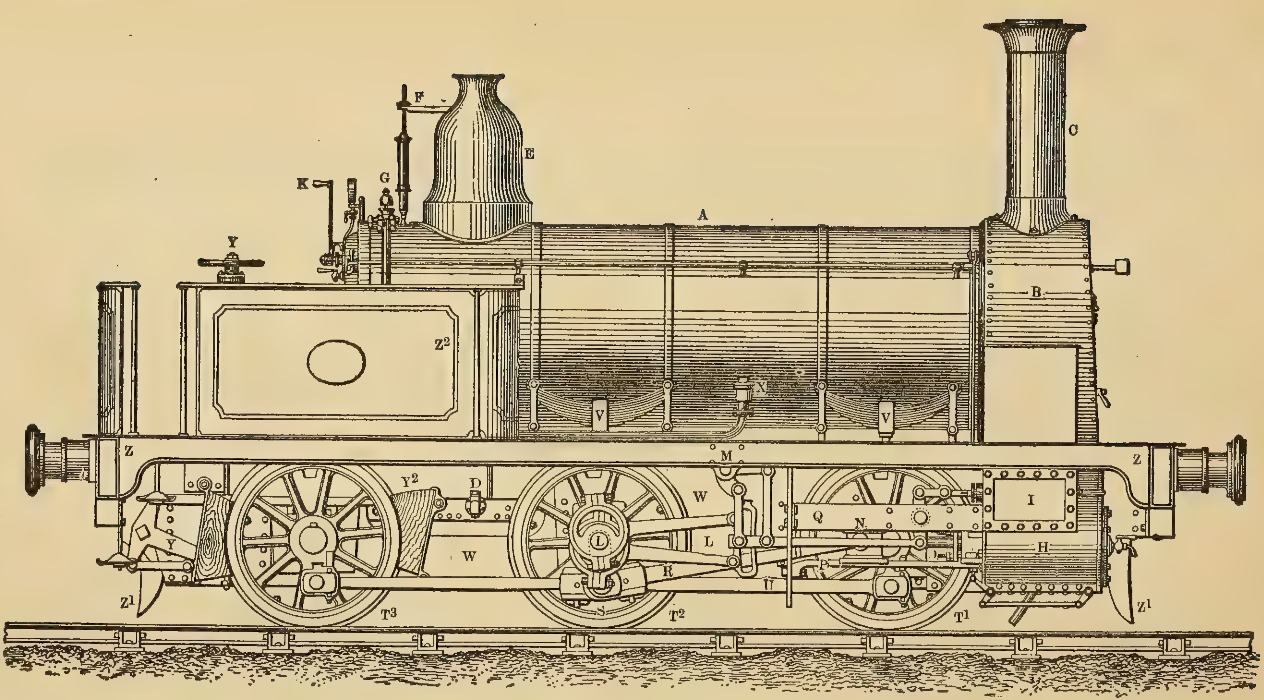


Fig. 546.—Tank Engine with Six Wheels coupled.

A, Boiler. B, Smoke box. C, Chimney. D, Blow-off tap. E, Steam dome. F, Safety valve. G, Steam whistle. H, Cylinder. I, Valve casing. K, Regulator handle. L, Eccentrics and link motion. M, Weigh shaft. N, Crosshead. O, Piston rod. P, Guide bars. Q, Steadiment for valve motion. R, Connecting rod. S, Crank pin. $T^1 T^2 T^3$, Leading, driving, and trailing wheels. U, Side rod. V V, Springs. W, Framing and tank. X, Check valve. Z, Platform, end beams, and buffers. Z^1, Rail guards. Z^2, Coal box.

EXPRESS ENGINE FOR THE PENNSYLVANIA RAILROAD

The following description of an express locomotive for the Pennsylvania Railroad is given by the *Engineer*, Feb. 10, 1882, as an excellent example of American practice. The boiler is of the wagon-top form, and is of steel; the grate is large, for burning anthracite coal, and therefore water tubes are used instead of fire bars.

Boiler:—	*Dimensions.*
Diameter,	4 ft. 2 in.
Length of grate, 10 ft.; Width of grate,	3 ft. 5¾ in.
Mean height of fire-box crown above grate,	3 ft. 1½ in.
Thickness of boiler plates,	⅜ in.
,, internal fire box,	¼ in.
,, tube plates,	½ in.
No. of wrought-iron tubes, 201; Inside diameter of tubes,	1⅝ in.
Length of tubes,	10 ft. 10¾ in.
Grate surface,	35 sq. ft.
Total heating surface,	1205 sq. ft.
Engine:—	
Diameter of driving wheels,	6 ft. 6 in.
,, bogie ,,	2 ft. 9 in.
Wheel base of coupled wheels,	7 ft. 9 in.
Total wheel base,	22 ft. 7½ in.
Diameter of axle boxes, 8 in.; Length of axle boxes,	10½ in.
Diameter of cylinders,	1 ft. 6 in.
Stroke,	2 ft.
Centre to centre of cylinder,	6 ft. 5 in.
Lap of valves,	1¼ in.
Width of ports, 1 ft. 4¾ in.; Length of ports,	1½ in.
Length of exhaust ports	3¼ in.
Weight full:—	
On drivers,	15 tons.
On trailers,	14 tons 3 cwt.
On bogie,	12 tons 4 cwt.
In all,	41 tons 7 cwt.

The tractive force is 100 lbs. per lb. of cylinder pressure.

HAULAGE POWER OF LOCOMOTIVES.

The following tabulated statement of the relative haulage power of locomotives is given by the *Railroad Gazette*. It is the result of experiments by an American railway commission, and includes three types of engine, viz. A. American locomotive with four driving wheels and 12,000 lbs. on each wheel, total weight of engine 36 tons. B. Ten-wheeled locomotive with six driving wheels and 12,000 lbs. on each wheel, total weight of engine about 42 tons. C. Eight driving wheels and 12,000 lbs. on each wheel, total weight of engine about 54 tons

Weights of Train which Locomotives can haul at a speed of 20 miles an hour under ordinary conditions, in tons of 2000 lbs. (not including the weight of Engine and Tender).

	Type of Locomotive.		
On straight track—	A	B	C
Level,	1096	1664	2226
Grade, 20 ft. per mile,	547	840½	1128
,, 40 ,,	350	545	734
,, 60 ,,	249	390½	522
,, 80 ,,	188	302	410
,, 100 ,,	148	242	330
On 5 deg. curves—			
Level,	921	1401½	1876
Grade, 20 ft. per mile,	464	716	962
,, 40 ,,	310	485	654
,, 60 ,,	227	360½	488
,, 80 ,,	173	279½	380
,, 100 ,,	137	225½	308
On 10 deg. curves—			
Level,	662	1013	1358
Grade, 20 ft. per mile,	401	621½	836
,, 40 ,,	278	477	590
,, 60 ,,	207	330½	448
,, 80 ,,	160	260	354
,, 100 ,,	128	212	290

SPECIFICATION FOR LOCOMOTIVE ENGINE AND TENDER.

As a good example of what such a document should be, we give the subjoined Specification for a bogie passenger engine and tender designed by Mr. W. Kirtley, locomotive superintendent of the London, Chatham, and Dover Railway. This class of engine differs in some respects from those previously in use on the line, and has frequently to work heavy trains at express speed.

The engines described in the following specification are known as class M. The following are their leading dimensions:—Diameter of cylinders, 1 foot 5½ inches: stroke of cylinders, 2 feet 2 inches; diameter of bogie wheels, 3 feet 6 inches; diameter of coupled wheels, 6 feet 6 inches; total wheel base of engine, 20 feet 11½ inches; total wheel base of tender, 12 feet; heating surface of tubes, 945·6 square feet; firebox, 107 square feet; total heating surface, 1052 square feet; grate surface, 16·5 square feet; capacity of tank, 2550 gallons.

Quality of Materials.—Where "brass" is specified it must be good tough metal. Gun metal must be composed of five parts of copper to one part of tin. White Metal.—This must be composed of—Tin, sixteen parts;

antimony, two parts; copper, one part and a half. Other materials to be obtained of the manufacture to be hereinafter specified, unless the consent of the Company's locomotive superintendent in writing be first obtained to an alteration.

Boiler.—Barrel, dome, fire-box casing, and smoke-box tube plate, and all angle irons, rivets, and stays to be made of Lowmoor, Bowling, Taylor's, or Cooper's (best Yorkshire) iron. Barrel to be telescopic, and made in two plates, the circumferential seams to be single rivetted, and the longitudinal seams to be butt-jointed, with inside and outside strips, double rivetted. Tube plate to be attached to barrel by a ring of angle iron, bored, faced, turned on edges, and shrunk on, and zigzag rivetted to both. The dome to be in one plate welded at the seam, and flanged at the bottom to fit barrel, to which it is to be double rivetted; a strengthening liner plate to be placed inside the barrel round the opening for the dome. The top to have an angle-iron ring rivetted to it, and to be fitted with a strong wrought-iron cover. The cover and angle iron must be accurately faced so as to make a perfectly steam-tight joint. Fire-box shell to be made as shown, the sides and top in one plate, the front or throat plate flanged forward and single rivetted to the barrel, and the back plate to the sides and top as shown. Angle irons for carrying the sling stays to be rivetted to the top in the position shown. The manhole to be of wrought iron, flanged top and bottom, and single rivetted to the casing, the top flange to be accurately faced to receive the safety valves. The boiler to be stayed by six longitudinal stays screwed into the back plate of the casing, and passing through the smoke-box tube plate, with nut and washer on either side, the back plate to be strengthened where the stays pass through by a liner plate rivetted to it on the inside. The longitudinal stays to be supported in the middle of their length in the manner shown. The fire-hole to be circular, the ring of the section shown to be Yorkshire iron, rivetted to the casing and fire-box plates, flush outside casing. The foundation ring to be Yorkshire iron, the corners of the form shown, carefully rivetted, so as to be thoroughly tight. Twenty-one brass taper mud plugs for washing out to be placed in the positions shown on the drawings.[1]

Dimensions.

	ft.	in.
Length of barrel	10	2
Diameter ,, outside at fire-box end	4	3
Thickness of barrel	0	$0\frac{7}{16}$
,, tube plate	0	$0\frac{7}{8}$

---

[1] These specifications are only supplied to selected firms of engine builders, who are invited to tender (upon the specification), and the drawings can be seen at the chief office of the Locomotive Engineer of the Railway Company. After a tender has been accepted, a complete set of detail drawings are supplied by the Company, and these have to be carefully worked to.

		ft.	in.
Thickness of dome plate		0	0$\frac{9}{16}$
Length of fire-box shell		5	9
Breadth ,, at bottom, outside		3	11
Depth ,, from centre line of boiler		5	2
Thickness ,, plates		0	0½
Section of foundation ring	3 in. × 2¾ in.	—	—
,, fire-hole ring	2 in. × 2⅜ in.	—	—
Diameter of rivets in boiler		0	0$\frac{13}{16}$
,, foundation ring		0	0⅞
Height of centre line of boiler from rail		7	2

Fire Box.—The fire-box plates to be of copper of the very best quality, obtained from Messrs. Everitt & Sons, Grenfell & Sons, Vivian & Sons, or other approved makers. The stays and rivets to be made from the very best soft rolled copper bars, by the same maker as the plates. The plates to be annealed both before and after flanging, and strips cut off must be tested by being doubled cold, without showing any sign of fracture, and also to be analyzed, and must not contain more than ·5 per cent. of impurities. The sides and crown to be in one plate, the crown curved as shown, and stayed with eight Yorkshire iron roof bars of the section shown, each secured by thirteen studs 1 inch diameter, screwed through the crown plate into the bar, with nut on the underside of the plate. Six of the roof bars to be connected to the angle irons on the casing plate by twelve sling stays of Yorkshire iron. Great care must be taken to bed the ends of the roof bars accurately on the fire-box plates, and that the sling stays are of the correct length, bearing on the pins top and bottom. The tube plate to be stayed to the barrel by six 1-inch copper stays, screwed through the plate into palm stays rivetted to the barrel. The copper stays to be screwed tightly into the fire box and casing plates, and neatly rivetted over at the ends, the thread being turned off the portion between the plates. A brass plug with fusible centre to be inserted in the crown of the fire box. A brick arch to be built in the fire box, supported on studs in the manner shown. Fire-box back plate to be dished at fire hole to meet the ring, and the fire hole fitted with air deflector scoop, and sliding doors, in the manner shown on the drawings. Fire grate to consist of nineteen wrought-iron fire bars and two cast-iron fire bars of the sections shown, supported on two cast-iron comb bar bearers by four wrought-iron brackets, studded to foundation ring. Fire box to be rivetted with best Yorkshire iron rivets.

Dimensions.

	ft.	in.
Length at top, outside	5	0½
Length at bottom, ,,	5	2
Breadth ,, ,,	3	4
Depth, inside	6	0
Water space at bottom, all round	0	3
Thickness of plates	0	0½

	ft.	in.
Thickness of tube plate	0 and 0	0$\frac{13}{16}$ 0½
Diameter of fire hole	1	4½
,, rivets	0	0$\frac{13}{16}$
,, copper stays	0 and 	0⅞ 1

Workmanship.—All the plates are to be planed or turned on the edges before being put together. The holes must be drilled or punched slightly countersunk, and rhymed out perfectly fair with each other in all plates and angle irons; drifting will under no circumstances be allowed. Care must be taken that the smaller diameters of the holes come together, that all burrs are carefully filed off, and that the plates are brought well together before any rivet is put in. All rivets must completely fill the holes, and the heads must be perfectly true and central. Any caulking that may be required must be done with a broad-faced tool, so that the plates may sustain no injury. Before being lagged the boiler is to be tested in the presence of the Company's locomotive engineer, or his inspector, to a pressure of 200 lbs. per square inch with water, and afterwards to 160 lbs. per square inch with steam, and it must be perfectly tight under these pressures.

Tubes.—To be of copper, solid drawn, of either Everitt's, Broughton Copper Company's, or other approved make, 9 B. W. G. at the fire-box end tapering to 12 B. W. G. at the smoke-box end. To be secured by a roller tube expander—great care being taken that the tubes are not cracked—and fixed with ferrules at the fire-box end. Ferrules to be of ferrule steel, and to go into the tubes a tight driving fit. The tubes are to project through the smoke-box tube plate $\frac{7}{16}$ inch.

Dimensions.

	ft.	in.
No., 199	—	—
Length between tube plates	10	6
Diameter, outside	0	1¾
,, ,, ... at smoke-box end for a length of 6 in....	0	1⅞
Thickness at fire-box end ... ... No. 9, B. W. G....	—	—
,, smoke box end ... ... No. 12, B. W. G....	—	—
Distance apart of centres, about	0	2½

Smoke Box and Spark Arrester.—Plates for smoke box and door to be of BB Staffordshire iron, having a perfectly smooth surface. The rivets are to be countersunk outside and filed smooth. Wrought-iron liners are to be placed against the tube plate, and the sides and front of the smoke box. The door to be dished as shown on drawings, and fitted with baffle plates and suitable dart, handles, and hinges, the latter to be finished bright.

A wrought-iron grate for arresting sparks to be supported in the smoke box in a horizontal position just below top of blast pipe. Care must be taken that this grate fits accurately round the steam and blast pipes.

Dimensions.

	ft.	in.
Length of smoke box, inside	2	8⅛
Width on centre line of boiler, inside	4	11
Thickness of plates	0	0⅜
Section of angle iron 2½ in. by 2½ in. by ½ in.	—	—
,, ring round door hole 3 in. by ¾ in.	—	—
Diameter of rivets	0	0⅝
Pitch of rivets, about	0	3

Chimney.—To be of BB Staffordshire iron; joint to be made with a butt strip, and the rivets to be countersunk, and filed smooth on the outside. The bottom, of best Yorkshire iron, to be quite free from hammer marks, and to be carefully fitted to smoke box. The top, of cast iron, to be made to drawing.

Dimensions.

	ft.	in.
Height of top of chimney from rail	13	3⅞
Diameter inside at top	1	6
,, ,, bottom	1	5
Thickness of plates	0	0¼

Ash Pan.—To be made to hold water; to be fitted with a damper, front and back, each to be worked separately from the footplate; the damper rods to be on the right-hand side of footplate.

Dimensions.

	ft.	in.
Thickness of plates of ash-pan	0	0$\frac{5}{16}$
Depth of ash-pan	1	2
Width	3	4

Safety Valves.—To be of the kind known as "Ramsbottom's duplex" safety valves, to be fixed on the fire-box casing. The columns to be of brass turned bright, fixed on a cast-iron manhole cover. The springs (of approved manufacture) and gear to be made accurately to drawing, and set so as to blow off at 140 lbs. per square inch. The seating to be of wrought iron, carefully fitted to the fire-box casing. All the joints must be accurately faced, so as to be perfectly steam-tight.

Dimensions.

	ft.	in.
Diameter of valves	0	3½
Distance apart of columns	0	10$\frac{5}{16}$
Height of brass columns	1	0¾
Diameter of spring steel	0	0$\frac{13}{16}$
,, manhole cover	1	6
Thickness of seat	0	1⅛

Regulator and Steam Pipes.—Regulator to be of cast iron, the head to be fitted with double valves. The steam pipes to be of copper sheets hard soldered together on the inside. Flanges and cone to be brass. Steam pipe in boiler to be fixed to tube plate by a turned ferrule of best steel and to regulator by means of three claw bolts. Elbow pipe in smoke box to be of cast iron.

Dimensions.

		ft.	in.
Diameter of steam pipes, inside		0	4½
Thickness ,,	No. 7, B. W. G.	—	—

Blast Pipe.—The blast pipe to be of cast iron, the top to be bored and turned to the form shown.

Dimensions.

	ft.	in.
Diameter of blast orifice	0	4¾
Height of blast pipe above top row of tubes	0	2

Frames, Inside.—Inside frames and front buffer plate to be Bessemer steel of Cammell & Co.'s, John Brown & Co.'s, Bolton Iron and Steel Co.'s manufacture, or other approved makers, solid rolled, and each plate must have the brand of the manufacturer legibly stamped on its outer side. The plates are to be planed all over on the inner side, and the outer side must be finished with a good smooth surface. All holes to be marked from one template, and drilled and rhymed out to the exact size given. The frames to be set in and thoroughly well stayed together by the buffer plate, and with plates and angle irons at the leading end in the manner shown on drawings, the front footplate to be thinned at the edges as shown. A plate is to be placed horizontally under the cylinders to carry the bogie pin, and must be firmly bolted to angle irons on the frames. A transverse stay arranged to carry the back ends of the motion bars and the intermediate spindle guides, and a vertical stay in front of the fire-box casing, must be placed in the positions shown. Over the trailing axle a horizontal flanged stay is to be securely bolted to the frames, and at the hind end of the frames a cast iron footplate arranged for the tender couplings, is to be placed. All these stay plates and angle irons to be of BB Staffordshire iron. The casting and the transverse stays must be securely fastened to the frames by turned bolts. The rubbing pieces for tender buffers to be well case-hardened. When finished the frames must be perfectly true and square in all directions. The footplate to be of steel, of the same make as the frames, and the rivets to be countersunk on the top. Guard bars of the form shown are to be securely bolted to the frames and buffer plates.

Dimensions.

	ft.	in.
Thickness of frames, finished	0	1
Depth over leading bogie wheels	1	3
,, between cylinders and driving horns	1	5½
,, between driving and trailing wheels, open	1	9⅞
Greatest depth of plates	2	11¾

	ft.	in.
Distance from centre of bogie to front end of frame	5	0
,, ,, ,, to centre of driving axle	9	9
,, ,, driving axle to centre of trailing axle ...	8	4
,, ,, trailing axle to hind end of frame ...	4	0
Extreme length of plates	27	1
Distance from centre of driving axle to front of fire-box casing	1	10⅛
Distance between frames at leading end	3	9
,, ,, from cylinders to trailing end	4	0
Height of top of frame from rail	4	1½
Depth of buffer plate	1	3
Length ,, ...	7	6
Thickness ,, ...	0	1⅜
Thickness of footplate	0	$0\frac{5}{16}$
Extreme width of footplate	7	10

Outside.—To be of Yorkshire angle iron—the step plates to be welded on—and to be stayed to the inside frames as shown on the drawings. All the rivets to be countersunk outside. Section of angle iron for frames 4 inches by 2½ inches by ½ inch.

Buffers and Draw Gear.—Buffers to have wrought iron cases and plungers, with "Timmis" unequal section steel springs, and to be in all respects similar to drawings supplied. Draw bar to be of best chain-cable iron, and to be fitted with a screw coupling, and to have an india-rubber spring (No. 6A), to drawing, of George Spencer & Co.'s make.

Dimensions.

	ft.	in.
Height of centre line of buffers from rail	3	5
Distance of centres of buffers apart	5	8
Diameter of draw bar	0	2

Cylinders.—To be made of the best close-grained, hard, and strong cold-blast cast iron, twice cast, as hard as can be worked, and perfectly free from honeycomb or other defects. They must be bored out perfectly true, the ends being bell-mouthed. The cylinders are to be made with loose covers at each end, the back cover having provision for carrying the front ends of the slide bars. All joints and faces to be machined and scraped to a true surface, so that a perfect joint can be obtained. When the cylinders are bolted together, they must be tested by hydraulic pressure to 250 lbs. per square inch. The cylinders to be horizontal, and to be attached to the frames by flanges—the holes in which and in the frames are to be rose-bitted—and secured by turned bolts a driving fit. The front flanges and covers are to project through the frames as shown on drawings. To be provided with waste-water cocks and gear worked from the left-hand side of footplate. The top of cylinders to be covered with thin fire-brick or cement; the bottom flanges to be planed perfectly true, so that the bogie pin-plate may bear truly against them.

Dimensions.

	ft.	in.
Diameter	1	5½
Stroke	2	2
Distance of centres	2	4
,, valve spindle centres	0	3½
Thickness of metal	0	0⅞
Length of ports	1	2
Width of steam ports	0	1½
,, exhaust ports	0	3½
Thickness of bridges	0	1
Length of working face	0	11
Distance from centre of driving axle to centre of exhaust port	9	9

Pistons.—To be of tough cast iron, made from cylinder metal, and to be sound and free from all defects. To be accurately fitted to cones on ends of piston rods, and fixed with nuts as shown on drawings. Piston heads to be turned $\frac{1}{32}$ inch smaller than bore of cylinder. Packing rings to be of cast iron, turned only on the outside and on edges, and made ½ inch larger in diameter than the cylinder bore, and then cut and sprung into their places. When finished the whole must be an easy but accurate fit in the cylinder, so that the piston and rod can be moved backwards and forwards by hand.

Dimensions.

	ft.	in.
Width of piston	0	3¼
,, rings, two in each piston	0	0½
Thickness of rings	0	0½

Piston Rod and Crosshead.—To be of the best mild cast steel, manufactured by Taylor Brothers, Vickers, Sons, & Co., Cammell & Co., or other approved makers, with cone and nut for fixing to piston; the crosshead to be solid with the rod.

Dimensions.

		ft.	in.
Diameter of rod		0	2¾
Length between cone and shoulder of crosshead		3	0⅞
Taper of cone in piston	1 in 3	—	—
No. of threads per inch piston end	6	—	—

Gudgeon Pins.—To be of best Yorkshire iron, keyed in the crossheads and well case-hardened.

Slide Bars and Slide Blocks.—Slide bars to be of cast steel from the same makers as piston rods, and to be provided with brass oil siphons to drawings. The slide blocks to be of cylinder metal, sound and free from all defects.

Dimensions.

	ft.	in.
Width of slide bars	0	3
Thickness ,,	0	2¼
Length ,,	3	9
,, of slide block	1	0
Distance between slide bars vertically	0	3⅜
,, ,, , horizontally	0	6⅞

Connecting Rods.—To be of best Yorkshire iron, forged solid in one length. The brasses to be of gun metal, those for the big ends to be lined with white metal. The cotters to be of steel, and the bolts of the best Lowmoor iron forged from the solid, the heads must on no account be welded on.

Dimensions.

	ft.	in.
Distance of centres	6	1
Diameter of big-end bearings	0	7¾
,, small-end bearings	0	3

Slide Valves and Valve Spindles.—The valves to be of phosphor bronze. The spindle frames and intermediate spindles to be of best Yorkshire iron, of the form shown on drawings, the latter to be well case-hardened.

The intermediate spindle guides to be of cast iron, bushed from either end with gun-metal bushes, and to have oil boxes cast on as shown.

Dimensions.

	ft.	in.
Lap of valve	0	1
Lead, in full gear	0	0$\frac{3}{32}$
Centre line of valve above centre line of cylinder	0	1
Diameter of valve spindle	0	1⅞
,, intermediate spindle	0	3½
Length of ,, ,, guides	1	0

Valve Motion.—The valve motion to be made from the best scrap iron, and the working and rubbing surfaces to be thoroughly case-hardened, and provided with oil siphons and grooves, and finished in the best manner. Expansion link to be supported at the top from the forward eccentric rod pin, the reversing shaft being below the motion and behind the link. The motion pins to be of best iron, thoroughly case-hardened and accurately fitted. Eccentric sheaves to be in two pieces, the smaller piece being of best scrap iron, and the larger piece of cylinder metal. Eccentric straps to be of wrought iron, solid with the rod, and to be fitted with white-metal liners.

Dimensions.

	ft.	in.
Length of expansion link between centres	1	4½
,, eccentric rods	4	7
,, lifting links	1	10⅝
Diameter of motion pins	0	1¾
,, eccentric sheaves	1	4¼
Throw ,, ,,	0	3¼

Reversing Gear.—Reversing to be performed by means of a screw arrangement, firmly supported on the right-hand side of footplate.

Coupling Rods.—To be of Bessemer steel of approved make, with solid ends and siphons, and to be fitted with phosphor-bronze bushes. Each rod to be forged solid in one length, and finished bright.

Dimensions.

		ft.	in.
Distance of centres		8	4
Section of rod	4½ in. by 1⅝ in.	—	—

Coupling Rod Pins.—To be of wrought iron case-hardened, accurately turned to gauge, and to be exact duplicates; to be turned to a taper of 1 in 50 and forced into the wheels by hydraulic pressure, the inner end to be afterwards rivetted over; the outside end of pin to be fitted with a screwed washer and taper pin, as shown on drawings.

Dimensions.

	ft.	in.
Diameter of pin	0	4
Length of bearing	0	4

Bogie.—To have four wheels, and to be in all respects of the form and dimensions shown on drawings. The frames to be of steel by the same makers as the engine frames (the brand to be on the outer side), raised as shown over the axles, the inner sides to be planed all over, and the outer sides where any attachment is made. The carrying girders to be of best Yorkshire angle iron bent round and securely rivetted to the frames, and machined on the outer sides, clearances being made where shown; steel bearing plates planed and scraped to a good working surface are to be rivetted to the angle irons. The ends of the frames are to be stayed by flanged plates of BB Staffordshire iron placed vertically, and bolted to the frames by the horn block bolts. When finished the frames must be perfectly true and square. The sliding block is to bear on the steel plates and work between the angle irons before mentioned, the side play being controlled by "Timmis" unequal section steel springs, arranged as shown on drawings. The bogie pin of wrought iron to have a projection on it fitting into a corresponding hole in the horizontal plate under the cylinders before mentioned, to which it is to be securely rivetted, and to have the end screwed with a washer nut secured by a taper pin through it. The sliding block to be of tough cylinder metal perfectly free from honeycomb or other defect; to be machined on all working and bearing parts, and to be scraped to a good working surface on the sliding portions, and to have lubricators fixed and oil grooves cut where shown. The spring cradles are to be made of best Yorkshire iron, with wrought-iron saddle pieces at each end, shaped to bear on the axle-boxes, and fitted with oil siphons as shown. The spring shaft to be of best Yorkshire iron passing through cast-iron bushes in the frames, with washer nuts and taper pins outside the spring buckles.

Dimensions.

	ft.	in.
Bogie wheel base	5	9
Thickness of frames, finished	0	0⅞
Depth at centre	0	10
„ horns	1	7¼

		ft.	in.
Length of frames		7	6½
Distance between frames		2	7¾
Section of angle iron for carrying girders,	7 in. by 5½ in. by 1 in.	—	—
,, steel bearing plates	6 in. by 3 in. by ½ in.	—	—
Length ,, ,,		2	5¼
Thickness of end stays		0	0½
Depth ,,		0	8
Total side play of bogie		0	1½
Diameter of bogie pin		0	6½
Section of iron for spring cradles	5 in. by 1 in.	—	—
Diameter of spring shaft		0	2½
,, check springs unloaded		0	3$\frac{15}{16}$
Length ,, ,,		0	10

Springs and Connections.—The springs to be of the very best spring steel, manufactured by Messrs. Turton & Sons, or other approved makers. Before being put in position each spring is to be fully tested until the camber is taken out, and the spring must afterwards resume its original form. The bogie springs are to be inverted, the buckles being connected direct to the shaft before mentioned, through the bogie frames; the ends of springs are to be connected to the spring cradles by hooks. The driving springs are to be under-hung, and the buckles are to be connected to the axle-boxes by T-links. The ends of the driving springs are to be connected to wrought-iron liners on the frames by adjustable links; the trailing springs to be "Timmis" unequal section steel springs, two under each axle box, arranged in the manner shown on the drawings. All the brackets, links, hooks, buckles, and pins connected with the springs must be of best Yorkshire iron, and the working surfaces must be thoroughly case-hardened.

Dimensions.

BOGIE.

		ft.	in.
Length loaded		4	0
Camber ,,		0	3
Breadth of plates		0	5
No. of ,,	14	—	—
Thickness of ,,		0	0½

DRIVING.

		ft.	in.
Length loaded		3	4
Camber ,,		0	3
Breadth of plates		0	4½
No. of ,,	13	—	—
Thickness of ,,		0	0½

Axle Boxes.—The axle boxes to be of the very best gun metal, lined with white metal, and fitted with cast-iron keeps and spring lubricating pads, and suitable covers. Every axle box must be made accurately to dimensions, so as to be interchangeable in any of the engines.

Horn Blocks and Horn Stays.—The horn blocks to be of crucible cast steel of Vickers', Cammell's, Taylor's, or other approved make; the bogie horn blocks to be fitted with cast-iron distance blocks and securing bolts as shown. The driving and trailing horn blocks to be solid, and provided with adjustable wedges and securing bolts. The horn blocks must be accurately bedded to the frames, and secured by turned bolts a driving fit. The horn stays to be of wrought iron; care must be taken that they fit the horn blocks accurately.

Axles.—To be of crucible cast steel of Vickers, Sons, & Co.'s extra make; the webs of crank axle to be hooped; all corresponding parts to be of an exact size and made to template, so that they may be interchangeable, and each axle must be clearly stamped with the maker's name, and the brand extra. The journals are on no account to be swaged down, but in all cases turned from the solid. The wheel seats must be accurately turned to a taper of 1 in 100.

Dimensions.

	ft.	in.
BOGIE AXLES.		
Diameter in middle ...	0	5¾
,, on wheel seats ...	0	7½
,, of journals ...	0	6
Length ,, ...	0	9
Distance apart of centres of journals ...	3	7
CRANK AXLE.		
Diameter in middle ...	0	7
,, on wheel seats ...	0	9
,, of journals ...	0	7½
Length ,, ...	0	7½
Diameter of crank-pin journals ...	0	7¾
Distance apart of centres of cranks ...	2	4
Do., journals ...	4	0
Cross sections of crank arms { 12 in. by 4¼ in. and 12 in. by 4½ in. } ...	—	—
Throw of cranks ...	0	13
TRAILING AXLE.		
Diameter in middle ...	0	7
,, on wheel seats ...	0	9
,, of journals ...	0	7½
Length ,, ...	0	7½
Distance apart of centres of journals ...	4	0

Wheels.—To be of wrought iron, of the best materials and workmanship, with solid rims, spokes, bosses, and balance weights. The spokes must be forged with solid T ends, and welded in the centre. The surfaces of rims and spokes to be shaped so that the wheels are exactly balanced. Each wheel is to be bored taper and put on the axle, before the tyres are shrunk on, by hydraulic pressure of not less than 60 tons, and then properly keyed on. Great care must be taken that the keys fit accurately.

Dimensions.

BOGIE.

		ft.	in.
Diameter on rim		3	0
Width of rim		0	4
Thickness of rim		0	1⅝
No. of spokes	10	—	—
Section of spokes at boss	4 in. by 1⅝ in.	—	—
„ „ rim	3½ in. by 1¼ in.	—	—
Diameter of boss		1	4
Width of boss		0	7
Diameter of hole in boss		0	7½

DRIVING AND TRAILING.

		ft.	in.
Diameter on rim		6	0
Width of rim		0	4¼
Thickness of rim		0	1¾
No. of spokes	20	—	—
Section of spokes at boss	4¼ in. by 1¾ in.	—	—
„ „ rim	3½ in. by 1⅜ in.	—	—
Diameter of boss		1	7
Width of boss		0	7½
Diameter of hole in boss		0	9
Centre of wheel to centre of coupling pin		1	0

WHEEL CENTRES.

	ft.	in.
Trailing to driving	8	4
Driving to centre of bogie	9	9
Bogie wheel base	5	9
Total wheel base of engine	20	11½

Tyres.—To be of crucible cast steel, of Vickers, Sons, & Co.'s extra manufacture, and to be of the section shown on drawing; to be shrunk on, and to be fixed to the wheel by lips on the outside, and by a wrought iron lip ring on the inside, of the section shown. Each tyre must be clearly stamped with the maker's name and the brand "Extra."

Dimensions.

BOGIE.

	ft.	in.
Diameter on tread	3	6
Width	0	5⅜
Thickness, finished	0	3
Distance between tyres	4	5⅞

DRIVING AND TRAILING.

	ft.	in.
Diameter on tread	6	6
Width	0	5½
Thickness, finished	0	3
Distance between tyres	4	5⅝

Cab and Splashers.—The cab and splashers to be made of best Staffordshire plate $\frac{3}{16}$ inch—full—thick, the former to be fitted with two plate-glass windows in brass frames, to be made to open. All rivets to be countersunk and filed smooth. A brass number plate, to pattern, is to be placed on each side of the cab.

Dimensions.	ft.	in.
Width of cab	6	6
Height at centre	7	0

Sand Boxes.—To be of cast iron, four in number, and fitted with valves and substantial gear for working from footplate. The leading boxes to be fixed on to the splashers of the driving wheels, and the valves are to be coupled together so as to work simultaneously.

Lagging.—The boiler and fire-box shell to be lagged with well-seasoned pine, and covered with smooth iron sheets—14 B. W. G.—supported on a light wrought-iron frame, and secured by belts in the usual manner.

Brake.—The engine to be fitted with the Westinghouse Automatic Brake, consisting of air pump, steam cock, 3 inch triple valve, release cock, ½ inch cock, driver's brake valve, air gauge, 10 inch by 24 inch reservoir and nipple, hose coupling and union, the whole of which are to be obtained of the Westinghouse Brake Co. The brake cylinder to be the L. C. D. R. standard pattern, 10 inches diameter. The brake shaft, hangers, brackets, rods, pins, crossbars and adjusting screws to be of the best scrap iron, the pins and working surfaces to be thoroughly case-hardened. Brake blocks to be of cast-iron, one to each wheel, and the whole arranged as shown on drawings.

Dome and Man-hole Casings, &c.—To be of the form shown on drawings, of charcoal iron 14 B. W. G. thick, thoroughly well finished. Brass moulding pieces are to be arranged round the back of smoke-box and fire-box casing.

Hand Rail and Lamp Irons.—A neat hand rail to be provided round the boiler, supported by polished wrought-iron standards. Lamp irons to be fixed on the smoke-box, footplate, and fire-box casing, in the positions shown.

Injectors.—Two injectors, Gresham & Craven's (brass), No. 8, to pattern, to be fixed on the ashpan sides in the position shown.

Boiler Mountings, &c.—A brass seating to be fitted to the fire-box casing, to carry two whistles and pressure-gauge cock. Two injector steam valves, screwed into brass seatings, to be fixed on the fire-box casing in the positions shown, with spindles through the weatherplate, and brass hand wheels inside of the cab. Pressure gauge to be Bourdon's manufacture (Paris), with solid drawn tube (to sample to be supplied), to indicate from 1 lb. to 200 lbs. per square inch. A blower to be fixed on right-hand side of smoke box, and worked from the footplate. Two glass water gauges, with asbestos packed cocks, two ball clack boxes, a Furness lubricator to each cylinder, a displacement lubricator, oil boxes for axle boxes and glands, lubricators for bogie sliding block, an ash-pan water cock, and a coal watering cock to be fixed in the positions shown on the drawings, the whole to be made of brass, in accordance with drawings, and of first-class finish.

Dimensions, &c., of Pipes.	Diameter inside.	Thickness B. W. G.
Main steam pipes in boiler and smoke box	4½ in.	7
Injector suction and delivery pipes	1¾ in.	10

	Diameter inside.	Thickness B. W. G.
Injector steam pipes	1¼ in.	10
Blower pipe in smoke box, copper solid drawn... ...	⅝ in.	12
Furness lubricator pipes in smoke box, copper solid drawn	⅜ in.	11
Oil pipes	5/16 in.	15
Pressure-gauge pipe, copper solid drawn	5/16 in.	15

Bolts and Nuts.—To be made to drawings and gauges, and all threads to be Whitworth's standard, except where otherwise specified or shown on drawings. Every nut of the same description, to be exactly the same size. Gland nuts to be case-hardened. All nuts in the smoke box to be of hard brass, and made with a cap. All union nuts to be made exactly to drawings.

No. of Threads per Inch.

Brass work of ½ in. diameter and upwards	12
Mud plugs	12
Copper fire-box stays	11
Piston rods, piston ends	6

TENDER.

Tank.—Tank to hold about 2550 gallons, to be of the horse-shoe form with a well, with angle irons, stays, man-hole, and coping as shown on drawings, to be constructed entirely independent of the frames and footplate. The whole of the plates, angle irons, and stays to be of BB Staffordshire iron. All the joints to be made with butt strips, and the rivets to be countersunk on the outside and filed smooth; care must be taken that the holes are perfectly fair with each other in all plates and angle irons, and that the rivets completely fill the holes. The man-hole to be fitted with a lid and strainer. Two water-tight tool boxes of wrought iron, lined with wood, are to be fixed on the tank. The mouths of feed pipes to be protected by copper rose boxes. The feed cocks of hard brass are to be provided with suitable sectors and handles worked from the footplate. The tank is to be fixed to the framing in the manner shown on drawings.

Dimensions.

		ft.	in.
Length of tank, outside		18	2
Width ,, ,, ...		7	1
Height ,, ,, ...		3	6
Between arms of horse-shoe		3	6
Length of ,, , ...		7	0
,, well outside		11	6
Width ,, ,, ...		3	6½
Depth ,, ,, ...		1	6
Height of coping above tank		0	10
Thickness of side, back, and coping plates		0	0¼
,, inside of horse-shoe and top and bottom plates ...		0	0 5/16
Section of angle iron for tank	2¼ in. by 2¼ in. by ⅜ in.	—	—
,, ,, ,, stays	2½ in. by 2½ in. by ½ in.	—	—

		ft.	in.
Section of stays	6 in. by ⅜ in.	—	—
Diameter of rivets		0	0½
Pitch ,,		0	1¾
Diameter of man-hole, inside		1	6
Height ,, ,, above tank		0	9

Frames.—Outside frames and buffer plates to be of steel, by the same makers as the engine frames; finished with a good smooth surface, angle irons of the section shown to be securely rivetted to the frames. Inside frames, vertical and horizontal transverse stays of BB Staffordshire iron, draw pin washers, and foot-steps, are to be placed as shown on drawings. All holes are to be marked from one template, and drilled and rhymed out to the exact size.

Dimensions.

		ft.	in.
Thickness of outside frame		0	0⅞
Depth ,, ,, open		2	11
Distance from front end of frame to leading axle		4	0
,, leading axle to middle axle		6	0
,, middle axle to trailing axle		6	0
,, trailing axle to hind end of frame		3	4
Extreme length		19	4
Distance apart		5	8½
Height of top of frame from rail		4	1½
Thickness of inside frame		0	0½
Depth ,, ,,	1 ft. 6 in. and	1	1
Length ,, ,,		17	6½
Distance apart		3	8
Thickness of vertical and horizontal transverse stays		0	0½
Section of angle iron for stays,	2½ in. by 2½ in. by ½ in.	—	—
Length of buffer plates		7	6
Depth ,, ,,		1	4
Thickness ,, ,, leading end		0	0¾
,, ,, ,, trailing end		0	1
Thickness of footplate		0	0$\frac{5}{16}$
Extreme width of footplate		7	10

Buffers and Draw Gear.—Buffers on trailing end of tender to be in all respects similar to those on the engine; buffer spindles at leading end to be of wrought iron case-hardened, and to be guided in cast-iron sockets. The draw bars, safety links, and coupling chains to be of best chain-cable iron. Trailing draw bar to have an india-rubber spring, No. 6, of George Spencer & Co.'s make, and to be fitted with a screw coupling.

Dimensions.

	ft.	in.
Distances of centres of buffer spindles apart	3	3
,, ,, buffers apart	5	8
Height of centre line of buffers from rail	3	5

Hand Rail, Pillars, Lamp Irons, &c.—A hand rail and pillar to be placed on each side of the footplate as shown, and fixed to the tank and footplate. Three lamp irons, one gong iron, pulleys for communication cord, and a brass number plate, to be fixed on the tank in position shown on drawings.

Springs.—Bearing springs to be of the very best spring steel, by the same makers as engine springs, and to be similarly tested. They are to be connected by links to brackets rivetted to the frames by turned cold rivets of Lowmoor iron. Brackets, links, buckles, and pins to be of best Yorkshire iron, and the working surfaces must be well case-hardened. A laminated buffing spring of similar quality to the bearing springs is to be arranged at the leading end of the tender, as shown on drawings.

Dimensions.

		ft.	in.
BEARING SPRINGS:			
Length, loaded		3	6
Camber ,,		0	3½
Breadth of plates		0	4
Thickness ,,		0	0½
No. of plates in leading and middle springs	11	—	—
,, ,, trailing springs	12	—	—
BUFFING SPRING:			
Length screwed up		3	3
Camber ,,		0	3½
Breadth of plates		0	4½
Thickness ,,	1 plate ½ in. and 17 plates ⅜ in.	—	—

Axle Boxes.—Axle boxes to be of good tough cast iron, and to be carefully fitted with gun-metal bearings lined with white metal, wrought-iron covers, and keeps of cast iron arranged for spring lubricating pads.

Horn Blocks.—Horn blocks to be of cylinder metal as hard as can be worked, secured to the frames by turned bolts a driving fit: they are to have cast-iron distance blocks and securing bolts, as shown on drawings.

Axles.—To be of crucible cast steel of Vickers', Cammell's, Taylor's, or other approved manufacture, all corresponding parts to be of the same size and made to a template, so that they may be interchangeable, and each axle must be clearly stamped with the brand and the maker's name. The journals must on no account be swaged down, but turned from the solid metal.

Dimensions.

	ft.	in.
Diameter in middle	0	6
,, on wheel seat	0	6¾
,, of journal	0	5¼
Length of journal	0	9½
Distance apart of centre of journals	6	4

Wheels.—To be of wrought iron, of the best materials and workmanship, with solid rims, spokes, and bosses. The spokes to be made in a similar manner to the engine-wheel spokes. The wheels to be put on the axles—before the tyres are shrunk on—by hydraulic pressure of not less than 60 tons, and then properly keyed.

Dimensions.

		ft.	in.
Diameter on rim		3	3
Width of rim...		0	4¼
Thickness of rim		0	1⅝
Number of spokes	11	—	—
Section of spokes at boss	4 in. by 1⅝ in.	—	—
,, ,, rim	3½ in. by 1¼ in.	—	—
Diameter of boss		1	2
Width of boss		0	7
Diameter of hole in boss		0	6¾

Tyres.—To be of crucible cast steel of Vickers', Cammell's, Taylor's, Monkbridge, or Bowling Iron Company's manufacture, of same section as driving and trailing tyres, and to be fixed to the wheels in a similar manner.

Dimensions.

	ft.	in.
Diameter on tread	3	9
Width	0	5½
Thickness (finished)...	0	3
Distance between tyres	4	5⅝

Brake.—The tender to be fitted with the Westinghouse Automatic Brake, consisting of 10-inch brake cylinder, 12 inch by 26 inch reservoir, 3-inch triple valve, release valve, ½ inch cock, brake pipe cock, drip cup, release spring and hose coupling, which are to be obtained of the Westinghouse Brake Co. The brake to be arranged so as to be worked independently by hand. The brake screw and handle to be placed on the left-hand side of the tender. The brake shaft, hangers, brackets, pins, rods, levers and adjusting screws to be of the best scrap iron. A cast-iron block to be applied to each wheel, and the whole arranged as shown on the drawings.

Bolts and Nuts.—To be similar in all respects to those used on engine.

Painting.—Each engine and tender is to be painted in the following manner.—The boiler, before being lagged, to receive one coat of boiled oil and one coat of thick red lead; the inside of tender tank to have two coats of thick red lead. The lagging plates, cab, splashers, outside frames, tank plates, and wheels to have one coat of lead colour; then to be thoroughly stopped and filled up and rubbed down, one coat of vegetable black, two coats of drop black, then to be panelled in slate colour and lined to pattern in vermilion, and afterwards to have four coats of best engine copal varnish, to be properly rubbed down between each coat. The buffers and buffer plates to be similarly prepared and painted vermilion, with the number of the engine in gold shaded black on the latter; inside of frames and axles to be finished with one coat of vermilion and two coats of varnish. The company's monogram L. C. D. R. to pattern to be painted on each side of the tender tank in shaded gold letters. The frames, smoke box, chimney, fire-box casing, ash pan, coal space, footplate, bottom of tank, brake work, &c., to have three coats of japan black.

RULES FOR THE LOCOMOTIVE ENGINE.

Effective pressure of the steam in the cylinder.—The effective pressure of the steam in the cylinder, cutting off at various grades, is as follows, assuming 100 lbs. per square inch as the pressure in the boiler:—

	Effective mean pressure.
Steam cut off at ¾ of the stroke of the piston, ...	90
,, ,, ⅔ ,, ,, ...	80
,, ,, ½ ,, ,, ...	69
,, ,, ⅓ ,, ,, ...	50
,, ,, ¼ ,, ,, ...	40

Tractive power of locomotive engines.—The tractive power of locomotive engines is found by squaring the cylinder diameter in inches, multiplying by the mean pressure of the steam in lbs. per square inch, and again by the length of the stroke in inches, and dividing the result by the diameter of the wheel also in inches. Hence the following formula:—

$$T = \frac{D^2.\ P.\ L.}{W}.$$

Where T represents the tractive power; P, mean pressure in lbs. per square inch; D, the diameter of the cylinder; L, the length of the stroke in inches; and W, the diameter of the driving wheel in inches.

Resistance of trains due to gravity on any incline.—The resistance of trains due to gravity alone, on inclines, which may be 1 in 25, 1 in 50, or 1 in 100, as the case may be, is found in lbs. per ton of train by dividing the constant 2240 by the gradient, which gives the resistance in lbs. per ton of train; hence with the preceding gradients we have—

$$\frac{2240}{25} = 89{\cdot}6 \text{ lbs. per ton of train.}$$

$$\frac{2240}{50} = 44{\cdot}8 \quad ,, \quad ,,$$

$$\frac{2240}{100} = 22{\cdot}4 \quad ,, \quad ,,$$

and so on according to the gradient or inclination of the rails.

Resistance of trains at different speeds.—To find the resistance of trains at different speeds, on a level line of railway, in lbs. per ton of load, square the velocity, and divide the result by the constant 171, adding 8 to the quotient. This will give the resistance in lbs. per ton of load on a level. Hence the formula—

$$R = \frac{V^2}{171} + 8 = \text{lbs. per ton of load.}$$

To find the load which an engine will take up a given incline.—To find the load which an engine of a given tractive power will take up an incline at a given velocity. Divide the tractive power of the engine in lbs. by the force of the resistance due to gravity and speed in lbs. per ton, and the quotient will be the load in tons, deducting the weight of the engine and tender. Hence the formula—

$$L=\frac{T}{G+R}-W=\text{the load of the carriages in tons.}$$

To show what must be considered in designing locomotive engines for steep gradients, we will take an example from actual practice. A line of tramways was worked by a contractor's locomotive of the ordinary description on various gradients, the heaviest being 1 in 11 for about 800 yards. The cylinders of the engine were 11 inches in diameter; the stroke of the piston, 18 inches; the four wheels were coupled, 2 feet 6 inches in diameter, and placed 4 feet 6 inches apart from centre to centre. The weight of the engine in working order was 10 tons, and it drew behind it a load of 13 tons up the gradient of 1 in 11. The pressure of the steam was from 90 lbs. to 100 lbs. per square inch. On an incline of 1 in 11 the resistance due to gravity would be 203·64 lbs. per ton, and taking the engine friction at 18 lbs. per ton, and the waggon friction at 10 lbs. per ton, we have the following total resistances to be overcome by the engine in ascending the gradient:—

		lbs.
Resistance due to gravity, 23 tons at 203·63 lbs., ...	=	4683·5
Engine friction, 10 tons at 18 lbs. per ton, ...	=	180
Waggon friction, 13 tons at 10 lbs. per ton, ...	=	130
Total, ...		4993·5

or, say 5000 lbs. The weight available for adhesion was 10 tons or 22,400 lbs., which would be diminished by one-eleventh on an incline of 1 in 11. The actual adhesive weight available in the incline would therefore be—

$$22{,}400-\frac{22{,}400}{11}=2036\cdot3 \text{ lbs.};$$

and the adhesion must therefore have amounted to very nearly one-fourth of the load on the wheels. An engine of the above dimension would develop a tractive force of

$$\frac{11^2\times1\cdot5}{2\cdot5}=\frac{121\times1\cdot5}{2\cdot5}=72\cdot6 \text{ lbs.}$$

for each pound of effective pressure on the inch of the pistons; and to overcome the tractive resistance of 5000 lbs. the effective pressure must then have been

$$\frac{5000}{72 \cdot 6} = 68 \cdot 6 \text{ lbs. on the inch.}$$

This pressure on the pistons could be readily maintained by a boiler pressure of 100 lbs. per square inch.

In another example of small-wheeled coupled engines on a short line, the heaviest gradient on which was 1 in 12 for a length of 360 yards, the engine, weighing 7½ tons, took up a train loaded, of equal weight as the engine, at a rate of from 4 to 6 miles per hour. The cylinders of the engine were 8 inches diameter; the stroke of the piston, 15 inches; there were four wheels, coupled, 27 inches in diameter, with a wheel base of 4½ feet. Steam pressure in the boiler 120 lbs. per square inch. So we have—

RESISTANCES.

		lbs.
Resistance due to gravity, 15 tons at 186·6, ...	=	2799
Resistance due to speed, 15 tons at 8·21, ...	=	123
Engine friction, 7·5 at 18 lbs. per ton, ...	=	135
Waggon friction, 7·5 at 10 lbs. per ton, ...	=	75
Total, ...		3132

$$\text{Tractive force per lb. on the inch of the piston, } \frac{8^2 \times 15}{27} = 35 \text{ lbs.}$$

$$\text{Steam pressure per lb. on the inch, } \frac{3132}{35} = 92 \text{ lbs.}$$

This pressure could be easily maintained, considering the steam pressure in the boiler is 120 lbs. per square inch.

Adhesive power of locomotives.—The adhesive force of locomotive engines is due to the load on the driving wheels, when they are not coupled; but for goods engines, and ordinary coupled passenger engines, the adhesive force is due to the weight on all the wheels that are coupled. The adhesive force per ton of load on the wheels varies from 600 lbs. per ton when the rails are in a good condition, to 300 lbs. per ton when they are in a moist and greasy condition. The adhesive force must be greater than the tractive power of the wheels on the rails, otherwise the wheels will slip; consequently, we consider that the weight upon the wheels should be so arranged as to give the full tractive power when the rails are in a moist or slippery state; in ordinary English weather this may be taken at 450 lbs. per ton of load on the wheels.

Distribution of the load.—The average distribution of the load on a six-wheeled engine may be found by multiplying the total weight of the engine by the following, assuming the total weight of engine to be 1—

PASSENGER ENGINES WITH THE DRIVING AND TRAILING WHEELS COUPLED.

Load on the leading wheels, multiply the total weight by.......	·30
Load on the driving wheels, ,, ,,	·46
Load on the trailing wheels, ,, ,,	·24
	1·

GOODS ENGINES WITH THE WHEELS ALL COUPLED.

Load on the leading wheels, multiply the total weight by...	·346
Load on the driving wheels, ,, ,,	·36
Load on the trailing wheels, ,, ,,	·294
	1·

To find the centre of gravity horizontally when the load on the axles and distance apart are given.

Four-wheeled engine.—For engines with four wheels, multiply the load on the driving axle in tons by the length of the wheel base in feet, and divide by the total weight in tons; the quotient gives the horizontal distance in feet of the centre of gravity from the other axle. *Note.*—When the loads on the axles are equal the centre of gravity lies half way between them.

Six-wheeled engines.—For engines with six wheels, multiply the loads on the fore and hind axles in tons, by their respective distances from the middle axle in feet, find the difference of the products found, and divide this distance by the total weight in tons; the quotient is the distance in feet of the centre of gravity from the middle axle, measured towards the axle, for which the greatest product was found. *Note.*—When the products are equal the centre of gravity lies exactly over the middle axle.

To find the loads on the axles, when the total weight, the distance of the axles, and the position of the centre of gravity horizontally, are given.

Four-wheeled engines.—For engines with four wheels, multiply the total weight in tons by the distance of the centre of gravity from the driving axle, and divide by the length of wheel base. The quotient is the load on the other axle in tons; and the difference of this and the total weight is the load on the driving axle in tons. *Note.*—When the centre of gravity is half way between the axles the loads on the axles are equal.

For engines with six wheels.—When the load on the middle axle is given, multiply the total weight in tons by the distance of the centre of gravity from the hind axle in feet. Multiply also the load on the middle axle by its distance from the hind axle; find the difference of these two products, and divide it by the wheel. The quotient is the load in tons upon the front axle; whence the load on the hind axle may also be found.

When the load on one of the axles is given, multiply the total weight by the distance of the centre of gravity from the other end axle, on which the load is unknown. Multiply also the given load by the wheel base; find the difference of these products, and divide it by the distance of the middle axle from the aforesaid end axle. The quotient is the load in tons upon the middle axle; whence the remaining load may be found.

Mem.—The conditions which chiefly control the arrangement of the axles are that there shall be a sufficiency of weight on the leading wheels for safely guiding the machine, and on the driving wheels for the purpose of traction. To illustrate this, we will take two engines of the passenger type, with and without coupled wheels, of which the following are the necessary data:—

	Six-Wheeled Passenger Engine, Single Driving Wheel in the middle or front of Fire Box.	Six-wheeled Engine, Driving and Trailing Wheels Coupled.
Wheel base,........................	12 ft. 0 in.	12 ft. 8 in.
Front to middle wheel,............	5 ,, 6 ,,	5 ,, 4 ,,
Middle to hind wheel,.............	6 ,, 6 ,,	7 ,, 4 ,,
Centre of gravity with respect to middle axle,................	6 in. before	4 in. behind
Total weight,.........................	19 tons.	19 tons 10 cwts.
Load on front axle,.................	5 ,, 15 cwts.	5 ,, 15 ,,
Load on middle axle,..............	9 ,, 15 ,,	9 ,, 0 ,,
Load on hind axle,..................	3 ,, 10 ,,	4 ,, 15 ,,

Tables showing the diameter of cylinders, stroke of the piston, diameter of wheels, and wheel base.

ENGINES WITH ALL THE WHEELS COUPLED.

Diameter of cylinders,..........	16 in.	16 in.	16 in.	18 in.
Stroke of the piston,............	24 ,,	24 ,,	24 ,,	24 ,,
Diameter of the wheels,........	54 ,,	60 ,,	60 ,,	57 ,,
Distance between driving and leading wheels,............	7 ft. 8 in.	6 ft. 9 in.	7 ft. 9 in.	7 ft. 1½ in.
Distance between driving and hind wheels,................	7 ,, 7 ,,	5 ,, 3 ,,	7 ,, 9 ,,	8 ,, 1½ ,,
Wheel base,........................	15 ,, 3 ,,	12 ft. *	15 ,, 6 ,,	15 ,, 3 ,,

* Engine marked thus, the wheels are all placed in front of the fire box.

ENGINES WITH THE DRIVING AND HIND WHEELS COUPLED.

Diameter of cylinders,..........	14 in.	15 in.	15 in.	18 in.
Stroke of piston,..................	20 ,,	22 ,,	20 ,,	24 ,,
Diameter of coupled wheels,..	66 ,,	63 ,,	66 ,,	73 ,,
Diameter of leading wheels,...	44 ,,	36 ,,	42 ,,	43 ,,
Distance between driving and leading wheels, ...	6 ft. 6 in.	7 ft. 6 in.	6 ft. 0 in.	6 ft. 1 in.
Distance between driving and hind wheels,.................	6 ,, 6 ,,	6 ,, 6 ,,	8 ,, 6 ,,	9 ,, 0 ,,
Wheel base,.........................	13 ,,	14 ,, *	14 ,, 6 ,,	15 ,, 1 ,,

* Engine marked thus is a tank engine, with a bogie truck in front, the distance between the driving and leading wheels is taken to the centre of the truck, the truck wheels being 4 ft. 6 in. apart from centre to centre.

ENGINES WITH THE DRIVING AND LEADING WHEELS COUPLED.

Diameter of the cylinder, ...	15 in.	16 in.	16 in.	16 in.
Stroke of the piston,............	24 ,,	20 ,,	20 ,,	22 ,,
Diameter of coupled wheels,	57 ,,	55 ,,	55¼ ,,	60 ,,
Diameter of hind wheels,......	42 ,,	43¾ ,,	42¼ ,,	42 ,,
Distance between driving and leading wheels,.............	6 ft. 9 in.	6 ft. 0 in.	6 ft. 2 in.	7 ft. 3 in.
Distance between driving and hind wheels, ...	6 ,, 6 ,,	7 ,, 0 ,,	7 ,, 1 ,,	7 ,, 3 ,,
Wheel base, ...	13 ,, 3 ,,	13 ,, 0 ,,	13 ,, 3 ,, *	14 ,, 6 ,,

* This is a tank engine.

ENGINES HAVING NONE OF THE WHEELS COUPLED.

Diameter of the cylinder,............	14 in.	15 in.	16 in.	16 in.
Stroke of the piston,.................	22 ,,	20 ,,	20 ,,	22 ,,
Diameter of driving wheels,.........	72 ,,	69 ,,	78 ,,	78 ,,
Diameter of front leading wheels, ... } Both placed in front of the driving wheels,	42 ,,	42 ,,	42 ,,	48 ,,
Diameter of back leading wheels, ...	42 ,,	42 ,,	42 ,,	48 ,,
Distance between driving and leading wheels, ...	5 ft. and 7 ft. 4 in.	5 ft. 10 in.	7 ft. 3 in.	7 ft. 9 in.
Distance between driving and hind wheels,................................	none.	7 ,, 4⅛ in.	7 ft. 3 ,,	7 ,, 3 ,,
Wheel base, ...	12 ft. 4 in.	13 ft. 2⅛ ,,	14 ft. 6 ,,	15 ,, 0 ,,

Tables of weight of six-wheeled engines taken from practice.

ALL THE WHEELS COUPLED.

Length of outside fire box, ...	4 ft. 4 in.	4 ft. 11 in.	5 ft. 2 in.
Length of body of boiler,.........................	14 ,, 0 ,,	10 ,, 6 ,,	10 ,, 6 ,,
Diameter of wheels,................................	5 ,, 0 ,,	5 ,, 0 ,,	5 ,, 0 ,,
Distance between driving and leading wheels,	6 ,, 11 ,,	7 ,, 4 ,,	7 ,, 9 ,,
Distance between driving and hind wheels,...	5 ,, 3 ,,	7 ,, 11 ,,	7 ,, 9 ,,
Centre of gravity in front of driving wheel centre,	0 ,, 7½ ,,	0 ,, 4¼ ,,	0 ,, 9½ ,,
Weight on leading wheels,........................	8½ tons.	10 tons.	10½ tons.
Weight on driving wheels, ...	9 ,,	9½ ,,	11½ ,,
Weight on hind wheels,...........................	8¾ ,,	8 ,,	7½ ,,
Total weight, ...	26¼ ,, *	27½ ,,	29½ ,,

* Engine marked thus has all the wheels in front of the fire box.

ENGINES WITH DRIVING AND HIND WHEELS COUPLED.

Length of outside fire box,	3 ft. 7½ in.	7 ft. 0 in.	3 ft. 9 in.
Length of body of boiler,	9 ,, 4½ ,,	8 ,, 6 ,,	11 ,, 0 ,,
Diameter of coupled wheels,	5 ,, 0 ,,	5 ,, 6 ,,	5 ,, 6 ,,
Diameter of leading wheels,	3 ,, 6 ,,	3 ,, 6 ,,	3 ,, 6 ,,
Distance between driving and leading wheels,	5 ,, 4 ,,	6 ,, 6 ,,	6 ,, 0 ,,
Distance between driving and hind wheels,	7 ,, 4 ,,	6 ,, 6 ,,	8 ,, 6 ,,
Weight on leading wheels,	5¾ tons.	6 tons 10 cwts.	8 tons 8 cwts.
Weight on driving wheels,	9 ,,	9 ,, 15 ,,	8 ,, 11 ,,
Weight on hind wheels,	4¾ ,,	7 ,, 5 ,,	8 ,, 10 ,,
Total weight,	19½ ,,	23 ,, 5 ,, *	25 ,, 9 ,,

* This engine has an inclined fire box, with hind axle placed underneath the box.

ENGINES HAVING NONE OF THE WHEELS COUPLED.

Length of outside fire box,	3 ft. 7½ in.	3 ft. 7½ in.	5 ft. 7 in.	4 ft. 10 in.
Length of body of boiler,	10 ,, 0 ,,	9 ,, 9 ,,	10 ,, 8 ,,	10 ,, 6 ,,
Diameter of driving wheels,	5 ,, 6 ,,	6 ,, 0 ,,	7 ,, 0 ,,	6 ,, 0 ,,
Diameter of leading and hind wheels,	3 ,, 6 ,,	3 ,, 6 ,,	4 ,, 0 ,,	4 ,, 0 ,,
Distance between driving and leading wheels,	5 ,, 9 ,,	5 ,, 6 ,,	7 ,, 1 ,,	7 ,, 3 ,,
Distance between driving and hind wheels,	7 ,, 0 ,,	6 ,, 6 ,,	7 ,, 7 ,,	7 ,, 3 ,,
Centre of gravity in front of driving wheel centre,	0 ,, 9¼ ,,	0 ,, 6 ,,	1 ,, 4 ,,	0 ,, 6¼,,
Weight on leading wheels,	5¾ tons.	5¾ tons.	11 tons.	8½ tons.
Weight on driving wheels,	9½ ,,	9¾ ,,	10½ ,,	12¾ ,,
Weight on hind wheels,	2¾ ,,	3½ ,,	5½ ,,	6½ ,,
Total weight,	18 ,,	19 ,,	27 ,,	27¾ ,,

Diameter of the cylinder.—To find the diameter of cylinder for a given tractive power, the mean pressure of steam in the cylinder, length of stroke, diameter of driving wheels being given. We certainly consider that locomotive engines should be bought and sold by the amount of tractive power they develop, suitable to the requirements. Supposing a tractive power of, say, 9216 lbs. is wanted, the mean pressure being 90 lbs. per inch, the length of the stroke of the piston 24 inches, and the diameter of the driving wheel, say, 60 inches.

To find the cylinder's diameter, multiply the tractive force by the diameter of the wheel, dividing the product by the mean pressure, multiplied by the length of the stroke of the piston, and the square root of the quotient will be the diameter of the cylinder, thus—

$$\frac{9216 \times 60 = 552960}{90 \times 24 = 2160} = \sqrt{256} = 16 \text{ inches diameter.}$$

CYLINDER PROPORTIONS.

Area of each steam port,	divide the cylinder area	in square inches by	10
Area of exhaust port,	,,	,,	6
Area of each steam pipe,	,,	,,	9
Area of main steam pipe,	,,	,,	6
Area of each blast pipe at bottom,	,,	,,	9
Area of blast orifice,	,,	,,	13

Length of steam and exhaust ports and opening by valve.—To find the length of the ports, divide the diameter of the cylinder by 1·2. The opening by valve is found by multiplying the area of the cylinder by the speed of the piston in feet per minute, dividing the product by the constant 10,000, this will give the area of the opening by valve in square inches.

Thickness of the cylinder.—To find the thickness of the metal in the cylinder, multiply the diameter by the steam pressure, as in the boiler, and divide the product by 120, this will give the thickness in sixteenths of an inch nearly.

Area of piston rod and depth of piston.—Multiply the area of the cylinder in sq. inches by the steam pressure per sq. inch, and divide the product by 4480, and the quotient is the area of the rod in sq. inches. For the depth of piston multiply the diameter of the cylinder by ·28.

Area of slide-valve rod and pins for valve motion.—To find the area of the slide-valve rod, divide the area of the valve face by 100, The pin for carrying the sliding block in link equals the diameter of the rod nearly, being a trifle more, the pin on eccentric rod end being of the same diameter; the rods are a third more in width than the diameter of the pin at the small end tapering to the eccentric end.

Maximum speed of piston.—For a speed of 40 miles per hour and upwards allow 15 feet of piston speed per minute for each mile per hour; thus at 40 miles per hour 15 × 40 = 600 feet per minute; at the same time, so long as an engine runs steadily, the speed of piston may be more.

Ratio of the diameter of cylinder to the stroke of piston.—The ratio of the diameter to the stroke of piston varies to suit the requirements; the usual proportion is as 3 to 4; thus for 15 inches diameter the stroke is 20 inches; while in some small engines suited for heavy gradients the diameter of the cylinder may be 8, 9, or 10 inches, the respective strokes being 15 inches.

Ratio of the stroke of piston to the diameter of driving wheels.—The ratio varies to suit the requirements; from 1 to 3½ to 1 to 4 work well for high speed on the rails. For lower maximum speed the ratio may be as 1 to 2; while for small engines suited for heavy gradients the stroke in some cases is 15 inches, the diameter of the wheels being 27 inches.

Number of cubic feet of water required to be evaporated for a given speed of engine per hour.—We will suppose a speed of 25 miles per hour is desirable with, say, 16-inch cylinders, stroke 21 inches, and 5 feet 6 inches the diameter of wheels.

To find the number of revolutions, multiply the number of feet in a mile by the speed in miles per hour, dividing the product by the circumference of the driving wheels, and the quotient gives the number of revolutions, thus—

$$\frac{5280 \times 25}{17{\cdot}3} = 7630 \text{ revolutions per hour.}$$

Now we will suppose the steam pressure is 90 lbs. per square inch, and that it requires 6 cubic inches of water to raise a cubic foot of steam at that pressure.

To find the number of cubic feet of water required.—Multiply the number of revolutions per hour by the cubic contents of both cylinders in feet for an entire revolution, and then by the number of cubic inches to raise a cubic foot of steam at 90 lbs. per square inch, dividing the product by 1728, gives the number of cubic feet of water required, thus—

$$\frac{7630 \times 9{\cdot}7 \times 6}{1728} = 256 \text{ cubic feet of water required.}$$

The boiler: proportions of fire-grate and heating surfaces:—

Area of fire grate.—Multiply the period of admission in hundreds of the stroke by ·0275, and add 1·75 to the product; multiply the sum by the tractive force due to the given dimensions of engine, and by the speed in miles per hour. Divide the product by 48,187. The quotient is the area of the fire grate in square feet.

Table giving the dimensions of fire grate, tubes, and diameter of cylinder, and length of stroke of the piston.

ENGINES WITH ALL THE WHEELS COUPLED.

Diameter of cylinder,	16 in.	16 in.	16 in.	16 in.	18 in.
Stroke of the piston,	24 ,,	24 ,,	24 ,,	24 ,,	24 ,,
Length of fire grate,	4 ft. 0 in.	4 ft. 0 in.	4 ft. 6 in.	4 ft. 3 in.	4 ft. 10½ in.
Breadth of fire grate,	3 ,, 5 ,,	3 ,, 5 ,,	3 ,, 5 ,,	3 ,, 6 ,,	4 ,, 8 ,,
Area of fire grate,....	13·6 sq. ft.	13·6 sq. ft.	15·5 sq. ft.	14·8 sq. ft.	27·5 sq. ft.
Number of tubes, ...	149	133	158	191	256
Diameter of tubes outside, ...	0 ft. 2 in.	0 ft. 2⅛ in.	0 ft. 2 in.	0 ft. 2 in.	0 ft. 2 in.
Length of tubes,.....	11 ,, 4 ,,	13 ,, 10 ,,	10 ,, 4 ,,	11 ,, 6 ,,	10 ,, 9 ,,

Heating surface.—To find the heating surface, multiply the number of cubic feet of water evaporated per hour by the area of the fire grate in square feet; find the square root of the product, which, multiplied by 21·2, gives the total heating surface in square feet.

SIX-WHEELED ENGINES, WITH FOUR WHEELS COUPLED.

Diameter of cylinder,	13 in.	14 in.	15 in.	15 in.	16 in.
Length of stroke,.....	20 ,,	20 ,,	20 ,,	22 ,,	20 ,,
Length of fire grate,	3 ft. 6½ in.	6 ft. 6 in.	3 ft. 0 in.	3 ft. 5¼ in.	3 ft. 6 in.
Breadth of fire grate,	3 ,, 5½ ,,	1 ,, 7¼ ,,	3 ,, 6 ,,	3 ,, 0¾ ,,	3 ,, 2 ,,
Area of fire grate,....	11·9 sq. ft.	19·25 sq. ft.	10·5 sq. ft.	10·52 sq. ft.	11 sq. ft.
Number of tubes,.....	158	210	150	145	212
Diameters of tubes,...	0 ft. 1⅞ in.	0 ft. 1¾ in.	0 ft. 1⅞ in.	0 ft. 1⅞ in.	0 ft. 1⅞ in.
Length of tubes,......	10 ,, 3 ,,	9 ,, 1¾ ,,	11 ,, 4¼ ,,	10 ,, 4 ,,	10 ,, 7 ,,
Fire-box heating surface,....	64 sq. ft.	107 sq. ft.	58 sq. ft.	65 sq. ft.	65 sq. ft.
Tube heating surface,	712·6	755	750	662	984
Total heating surface,	776·6	862	808	727	1094

To find the cubic contents in feet and area in square feet of the body of the boiler approximately: dividing the cubic contents of both the cylinders in inches by 80 will give the cubic contents of the body of the boiler, which, being divided by the length of the body, will give the area in square feet approximately.

Strength of boiler.

TABLE OF THE WORKING STRENGTH OF JOINTS.

	Best Yorkshire.	Best Staffordshire.
	lbs.	lbs.
Scarph welded,..............................	1,000	9000
Double rivetted, double welt,..........	9,000	7000
Double rivetted lap,........................	8,000	6500
Lap welded, ...	7,400	6000
Double rivetted, single welt,...........	7,300	6000
Single rivetted lap,..........................	6,700	5400

Body and round parts of boiler.—To find the working steam pressure due to a given diameter, thickness of plates in decimal parts of an inch, and particular kind of joint; multiply the thickness of plates in decimal parts of an inch by 2 — and by the working strength of the longitudinal joint in pounds per square inch as above; and divide by the diameter of the body in inches; the quotient is the working pressure of the steam in the boiler in pounds per square inch.

To find the thickness of plates in decimal parts of an inch due to a given diameter, particular kind of joint, and working pressure; multiply the working pressure of steam in pounds per square inch by the diameter in inches, and divide the product by the working strength of the longitudinal joint in pounds, and then again by 2; the quotient is the required thickness in decimal parts of an inch.

Flat parts of boilers.—The strength of the flat parts of boilers depends entirely on the strength of the stays, which are arranged at regular intervals, dividing the surface into segments, which may be reckoned as one segment to each stay. The fire-box stays are arranged in squares, pitched equally.

To find the working steam-pressure due to a given diameter of the rod, and area of segment stayed, the working tensile strength of best iron rods being as follows:—

⅞ inch diameter,	8,000 lbs.
1 inch diameter,	10,000 ,,
1⅛ inch diameter,	13,000 ,,

If the section of the rod is reduced by screwing, 10 per cent. is deducted from the working strength.

Divide the working strength of the tie rods in pounds by the area of the segment in square inches; the quotient is the working steam pressure in pounds per square inch.

To find the area of segment due to a given diameter of tie rod and working pressure, divide the working strength of the tie rod in pounds by the steam pressure in pounds per square inch; the quotient is the area of the segment in square inches.

Screwed stays.—Screwed bolts are generally pitched in squares or right angles.

To find the working pressure due to a given pitch, screwed and rivetted into the plates, the solid diameter of the stays being ¾ inch, the working strength being as follows:—

Copper stay bolt in copper plates,	3200 lbs.
Iron stay bolt in copper plates,	4800 ,,
Iron stay bolt in iron plates,	5600 ,,

Divide the working strength of the stay in pounds by the product of the pitches, multiplied together horizontally and vertically; the quotient is the working pressure in pounds per square inch.

To find the pitch of the stays due to a given pressure, divide the working strength of the stay bolts in pounds by the working pressure in pounds per square inch, and find the square root of the quotient, the result is the pitch in inches. *Note.*—The working strength cannot be materially affected by the thickness of the plates.

Pitch of the stays in the fire box.—The pitch of the stays varies from 4 inches horizontally and 5 inches vertically to 4½ inches each way for iron stays. For copper stays from 4 inches each way to 4¼ inches each way, and some have been pitched 3½ one way and 4 the other way.

Roof stays of the fire box.—To find the pressure carried by the roof stays of the fire box, multiply the span of the roof in inches by the pitch of the stays in inches, and by the pressure in pounds per square inch, and divide by 2240; the quotient is the pressure uniformly distributed, borne by each roof stay in tons.

To find the working strength of a roof stay of given dimensions, fixed in its place, multiply the thickness of the stay at the centre in inches by the square of its depth at the centre in inches, and by 30, and divide the product by the length of span in inches; the quotient is the working load, equally distributed in tons, when the stay is fixed in its place.

Note.—The side plates of the fire box sustain part of the pressure on the roof, and consequently the whole pressure, as calculated for the roof stays, errs on the safe side.

WEIGHT AND STOWAGE OF FUELS, &c.

Kind of Fuel.	Weight per foot.	Stowage weight per cubic foot.	Space to stow 1 ton.	Weight of water evaporated per lb. of fuel.	Equivalent fuel to evaporate the same weight of water. Coal being 1·0.
	lbs.	lbs.	cubic feet.	lbs.	ratio.
Coal, ...	80	51	44	9	1·0
Coke, ...	63	28	80	9	1·0
Pine, ...		21	107	2½	3·6

Area for safety valves.—To find the diameter of each valve, two being fitted, multiply the number of square feet of heating surface in the fire box by 144, dividing the product by 450, and one half of the quotient is the area for each valve in square inches; thus, for 68 square feet of heating surface in the fire box—

$$\frac{68 \times 144}{450} = 21 \cdot 7 \div 2 = 10 \cdot 8 = \text{say, } 3\tfrac{11}{16} \text{ diameter.}$$

The spring balance represents a weight of 100 lbs. more or less according to the pressure required, and the length of the lever is calculated in the first instance to the greatest amount of total pressure upon the valve. Thus, with an area 10·8 and 100 lbs. steam pressure, the distance of the centre of valve from the short end of the lever being 3·5 inches, we have—

$$10·8 \times 100 \times 3·5 = 3780 \div 100 = 37·8,$$

The total length of the lever from the stud to the spring balance.

Diameter of the feed pump.—Find the cubic contents of the steam cylinder in feet for an entire revolution, multiply the result by the number of cubic inches of water required to raise a cubic foot of steam at the required pressure, divide the product by the stroke of the pump in inches, then multiply the quotient by 1·5; this will give the area of the pump. Then, by a table of areas, you can find the diameter.

This is when the stroke of the pump equals that of the steam cylinder, two pumps always being fitted. We will take an example. The diameter of the cylinder being 16 inches; stroke of piston, 24 inches; steam pressure, 100 lbs. per square inch, requiring 6·6 cubic inches of water to raise a cubic foot of steam at that pressure, thus—

$$\frac{1·396 \times 4 \times 6·6}{24} = 1·53 \times 1·5 = 2·29, \text{ say } 1\tfrac{3}{4} \text{ inch diameter.}$$

The Giffard injector.—When Q represents the quantity of water injected in gallons per hour; P, pressure of steam in atmospheres; D, diameter of throat in inches—

$$D_{\circ} = ·0158 \sqrt{\frac{Q}{\sqrt{P}}}$$

$$O = (63·4\ D)^2 \sqrt{P}$$

Diameter of throat in decimal of an inch.	Delivery in gallons per hour with a pressure per square inch as under:—				
	30 lbs.	60 lbs.	90 lbs.	120 lbs.	150 lbs.
·1	56	80	98	113	127
·15	127	180	221	255	285
·2	226	321	393	455	508
·25	354	502	615	711	793
·3	505	722	884	1021	1140

Area of axles and boxes.—To find the area of cranked axle: multiplying the total weight on the axle by 3·5, will give the area at the pin, and for plain axles by 2·9, will give the respective areas in square inches. The cranked axle at centre may be ½ inch less in diameter, as likewise the diameter of the inside journals. The outside journals may be 1 inch less than the pin in diameter; for the length of the outside journals multiply the diameter by 1·36; in some plain axles the length of the journal is the same as the diameter. The distance between the jaw of the cranks is bare $\frac{1}{16}$ inch less than the connecting rod brasses, the thickness of the jaws in direction of the length of axle is three-fourths the diameter of the pin. The raised part for taking the wheels may be 1 inch larger in diameter than the inside journals, the length being equal to the diameter. The bearing surface or top brass in the axle boxes should have a surface of not less than 18 square inches for every ton on total load on the axle. For ordinary sides of, say, 5½ diameter of axles the brasses are ¾ inch thick at top and ½ inch at side, and the axle box 1¼ inch thick at top and 1 inch at side.

Dimensions of wheels.—For ordinary 5-feet wheels, all of wrought iron, the eye of the wheel is 7 inches, the length of the boss 6¾ inches, the greatest thickness of boss is struck with a radius equal to the diameter of the eye from the centre line. The spokes are flat, 3 inches broad at point and 3½ inches at the boss, and from 1⅛ to 1¼ thick at point, and from 1⅜ to 1½ inch at boss. The pitch of the spokes at the inside tyre or trod is 11 inches on the average. The inside tyre, 5¼ inches broad, by 1⅜ at middle and ⅞ inch at edge. The outside tyre, $2\frac{5}{16}$ inches in thickness at middle. The flanges about ⅞ inch deep and ⅝ inch broad for driving wheels, and 1¼ inch deep and 1¼ broad for leading and driving wheels.

For 3-feet wheels all of wrought iron: eye 6 inches diameter; length of boss, 6¾ inches; diameter of boss, 10½ inches; spokes, 1 to 1⅛ thick at point and 1¼ to 1⅜ inch thick at boss. The inside tyre 5¼ by 1⅛ inches, and the outside tyre 5¼ by 1⅞ inches, the number of spokes being ten.

Dimensions of springs and harness.—Ordinary springs, when loaded, are 2 feet 8 inches from centre to centre, and when unloaded 2 feet 7¼ inches, having a set of 5¼ inches from centre of scroll to top of plates, the breadth of the plates being usually 4 inches. To find the depth of the spring, multiply the constant 8·5 by the total load on the axle in cwts., then by the length of the spring in inches when loaded, dividing the product by the breadth of the spring in eighth parts of an inch, and the square root of the quotient is the depth in eighth parts of an inch. Top plates, $\frac{3}{8}$ inch thick at middle, and ½ inch at ends; all the other plates, $\frac{5}{16}$ inch in thickness; suspension pins, 1 inch in diameter; eye, 2¼ inches diameter.

To find the area at the bottom of the thread for tension rods of spring harness, divide the total weight on the axle by 4, and then by 2, and the quotient will be the area at the bottom of the thread, adding the thread gives the total diameter. The compressive pin in steel equals the total diameter of the tension rods. When fitted with side links, the suspension pins being, say, 1 inch in diameter, the side links may be 1½ inch broad and ⅝ inch in thickness.

Dimensions of framing.—The minimum dimension of framing for a goods engine with six wheels, all coupled, 5 feet in diameter, is 9 inches broad by ⅞ inch in thickness for inside frame, and 9 inches broad by 1 inch in thickness for outside frame, the horn plates being ½ inch in thickness, rivetted to the outside beams, forming the framing, the inside and outside beams being strongly bracketted together, and the horns stayed together, and diagonally to the end beams with flat stays, 2¾ × 1 inch in thickness. For ordinary passenger engines the minimum dimension of the inside frame is about 12 inches in depth, and for the outside frame, 9 inches in depth for plain bars, the horns being forged on. Of course there are a variety of frames made much deeper and cut out to lighten them. The front and end beams of oak may be from 5½ to 6 inches thick and 12 inches in depth, strengthened with corner plates, angle iron, &c.

Area of crosshead, motion bars, &c.—To find the area of the gudgeon of crosshead, divide the area of the cylinder by 28, this will give the area in square inches. To find the area of the slide-block pin in square inches, divide the area of the cylinder by 80. The thickness of the brass blocks is about ½ inch, this, supposing the pin to be 1¾ inch, will give 2¾ inches to the depth of the sliding or guide blocks; for the length of the sliding blocks multiply the diameter of the pin by 5·8. For the breadth of the motion bar take $\frac{1}{12}$ less than the diameter of the gudgeon for crosshead, when double motion bars are used, thickness of the motion bars one-half of the diameter of crosshead.

Or treating the motion bars as a beam and allowing one-third of the pressure on the piston as the thrust, multiply this thrust by the distance between the points of support in feet, dividing the result by the constant 1338 (for iron) multiplied by the total breadth; then the square root of the quotient will be the depth of the bars. For bolts one-third of the total pressure on the piston by 4000 gives the total area of the bolts at the bottom of the thread.

Area of connecting rod.—To find the area of the small end, multiply the area of the piston by the steam pressure in pounds per square inch, and divide by 4000 for the area at the small end, the breadth being equal to the diameter of the gudgeon of the crosshead. For the breadth at the crank end, multiply the breadth at the small end by 1·5 for connecting rods of about 6 to 1 of the crank. The breadth of the large butt is regulated by the diameter of the crank pin; for the thickness of the butt multiply the thickness of connecting rod by 1·42. The breadth of the jibs and keys at the large end equals the breadth of the rod at that end; for the thickness of the keys divide the thickness of the butt by 3·3. The breadth of the jibs and keys at the small end equals the breadth of the rod at that end, and the thickness is the same as for the large end; the area of the butt across the key way being equal, at least, to the area of the piston rod; the same holding good as regards the smallest area of the straps at the key ways.

Outside cranks and side rods.—The diameter of the crank pin equals the diameter of the gudgeon for crosshead, the length of the crank pin being ⅜ inch or so longer than the diameter. The diameter of the large eye may be ¼ inch smaller than the main crank pin as for cranked axles; for the thickness at eye multiply the diameter of the eye by ·3; for the breadth of the eye multiply the thickness by 2; for the breadth of the web divide the breadth of the eye by 1·4; the sides of the web are straight lines drawn from the extreme diameters at each end. There is one large steel key let into the web, 1¼ by $\frac{13}{16}$ inch, and two other keys, 1¼ by $\frac{5}{16}$ inch; for eyes, say, 6¼ inches in diameter.

The breadth of the body of the outside rods equals the diameter of the crank pin, tapering to the centre of body; the thickness should be regulated to give an area equal to nearly that of the piston rod; the thickness of the butts should not be less than the rods at the key ways, and their breadth 1 inch less than the length of the crank pin. The diameter of the steel coupling pin for the rods, when six wheels are coupled, may be one-third less than the breadth of the rod at end; the diameter of the eye being twice the diameter of the pin, and the thickness one-half of the diameter of the pin. The thickness of the brasses is ⅞ inch or so at ends, and ⅜ inch at sides. The keys are about 12 inches long, tapering from 1⅛ to 1¾, and ⅝ inch in thickness, for crank pins 3 inches in diameter.

All the minor details in the locomotive engine, such as handles, rods, pins, &c., should have ample strength, more so than what is usually allowed in any other class of engine, so that the parts may not vibrate or bend with the hand power applied. In the foregoing rules we have given the leading formulas required, and which are in general practice; the numerous engravings throughout this section clearly show the details of handles, pins, and other minor parts without further investigation.

ROAD LOCOMOTIVE OR TRACTION ENGINE.

Road Locomotives or Traction Engines have been used now for some time with good results. In large towns they are most useful for the haulage of heavy loads, which formerly could only be accomplished by a large number of horses; for agricultural purposes they have been used for some time, and extensively in India for the haulage of trains along the roads there both with goods and passengers. One of the essential features of a road steamer is the tyres of the wheels and the method whereby the engine is connected with the driving wheels. One great advance was made by the introduction of india-rubber tyres by Mr. Thomson of Edinburgh, whose road steamers with india-rubber tyres proved very successful, some of his engines being purchased by the Indian Government, and a regular service of trains was started in the Punjab as far back as 1873. These india-rubber tyres lessened the objectionable vibration of the engine and gave a high percentage of adhesion. The tyres are protected by iron shoes.

The engine is connected with the driving wheels by means of spur gearing working on a counter shaft, by means of which fast or slow speeds can be obtained by throwing suitable pinions in or out of gear. These pinions are either made of malleable cast iron or of crucible steel.

The boilers are sometimes of the vertical Field arrangement, the engines being also placed vertically. In others the boiler is horizontal, the machine not differing much in appearance from a railway locomotive. The wheels number either three or four, there being two large as drivers and one or two for guides; these latter wheels are steered by the driver or attendant by suitable gearing.

The speeds obtained by such engines necessarily vary with the load, but in some cases speeds of 10, 16, and even as high as 22 miles per hour are obtained, and with a train of carriages about 5 miles per hour over fairly steep gradients. The working expenses are necessarily varied, being from 1¼*d.* to 3*d.* per ton per mile.

Mr. R. E. B. Crompton, in a paper read before the Institution of Mechanical Engineers on this subject, says, "It cannot be denied that the question of improved and cheapened haulage on our tramways and streets is one of great importance for engineers and to the public. Now when we consider the inconvenience to ordinary wheeled vehicles of the present system of tramways when laid down in crowded thoroughfares, the high frictional resistance of the cars on the unmechanical tram rail, the liability to derangement of all street traffic by the derailment of the cars or the accidental breakdown of any other vehicle on their line; and when we contrast with this the traction engine, with its extreme handiness in turning and steering, its high adhesion, its minimum of harm done to the road surface, &c.; does it not point to the use of real railways of light construction carried as far towards the crowded centres as traffic will permit, and from thence onwards the hauling of the cars by such engines as have been here described, but of lighter construction and capable of being readily steered and worked in with the regular traffic?"—The following are the dimensions of engines as used by Mr. Crompton:—

	ft.	in.
"Length of engine and tender, ...	31	10
,, engine only, ...	16	0
Extreme width of engine, ...	8	8
,, height to top of spark-catcher, ...	13	4
Outside diameter of driving wheels (original), ...	6	2
,, ,, ,, ,, (altered), ...	6	6
,, ,, steering wheels, ...	3	10
Width of driving wheels, outside armour, ...	1	7
Diameter of cylinders, ...	0	8
Stroke of ,, ...	0	10
Diameter of crank shafts, ...	0	4
,, counter shafts, ...	0	3½
Average pressure of steam—lbs. per sq. in., ...	160	—
Ratio of gearing, fast speed, ...	3·75 to 1	—
,, ,, slow speed, ...	12 ,, 1	—
,, ,, ,, (altered), ...	8 ,, 1	—

It appears that the wear of the india-rubber tyres is on the *inner* surface, which appears to be so far prevented by black-leading the rubbing surface, but better still by preventing the slipping of the tyre by making depressions on the wheel.

The traction engine has been used instead of horses for tramway purposes; in some cases, however, the tramcar has the engine placed at one end, so that one vehicle only is used.

PORTABLE ENGINES.

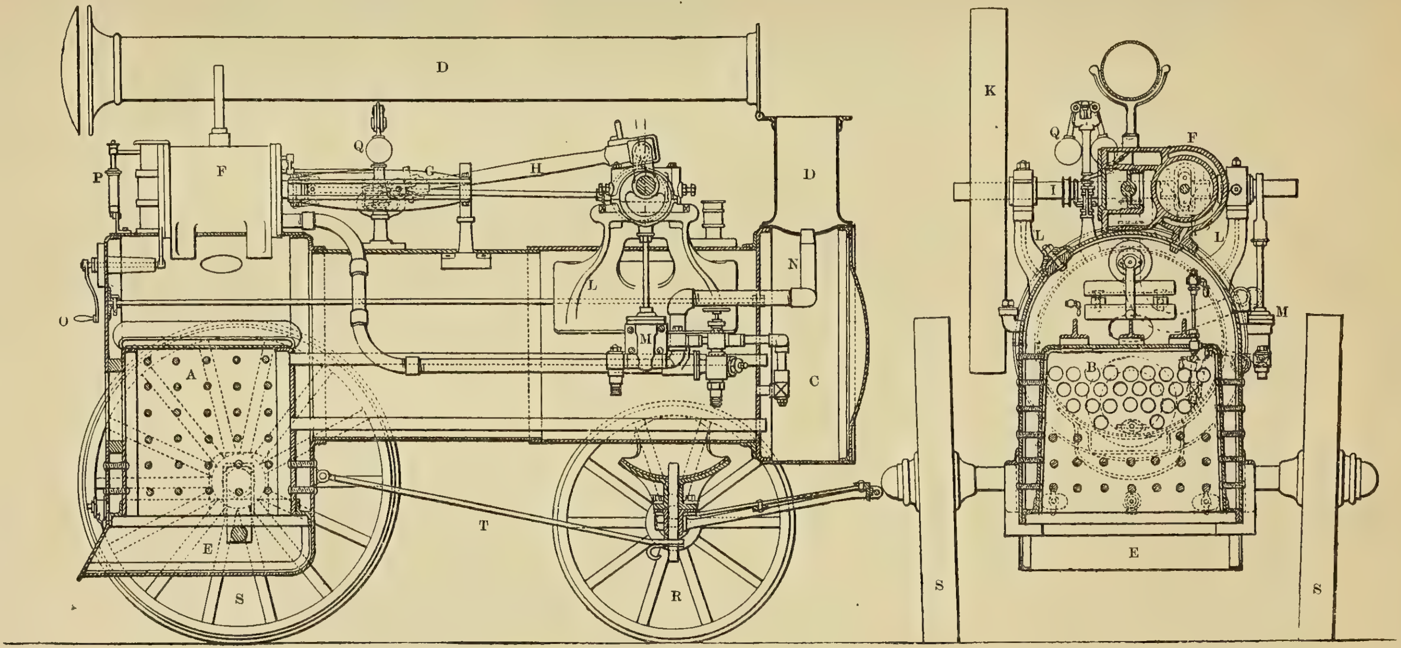
(See PLATE.)

Portable Engines are now much used for agricultural and other purposes. They consist essentially of locomotive boilers, having an engine placed on the top, and connected with a fly-wheel, which serves for transmitting the power to any machine by means of belting; the whole is set on wheels with broad tyres, by means of which it may be readily shifted from place to place. Single-cylinder engines of this class work up to about 10 horse-power; the double-cylinder arrangement being made up to 20 horse-power. The total weight of course varies with the power,—a five-horse power engine being about 3 tons, and a ten-horse power 5 tons.

The great point to be aimed at with such engines is economy and durability, ample boiler power, and a steady base for the boiler and engine to rest on.

Our Plate shows vertical and transverse sections of an eight-horse power Portable Engine of approved construction. The boiler is made of best plates (3/8 in. thick) and strongly stayed, with an ample allowance of heating surface; and each boiler is tested to a pressure of 120 lbs. per sq. inch before it is used. The fire box is of best Yorkshire plates (3/8 in. and 5/8 in. thick), with a large grate surface. The cylinder is 9¾ inches in diameter, with a stroke of 12 inches, and is furnished with a steam jacket. The piston and valve rods are both of steel. There is no steam joint between the cylinder and the boiler; the governor, which is both powerful and sensitive, acts direct upon the throttle valve. The feed pump is placed vertically, and is constantly at work whilst the engine is running, either circulating the water through the heater or forcing it into the boiler. The feed-water heater heats the water to nearly

PORTABLE ENGINE.



A Fire Box.
B Tubes.
C Smoke Box.
D Funnel.
E Ash Pan.

F Cylinder and Valve Casing, &c.
G Motion Bars, Crosshead, &c.
H Connecting Rod.
I Cranked Shaft.
K Fly Wheel.

L L Brackets for carrying the Cranked Shaft.
M Feed Pump driven by an Eccentric.
N Blast Pipe.
O Regulator Handle.

P Safety Valve.
Q Governor.
R Front Wheels with Swivelling Axle.
S Back Wheels with Fixed Axle.
T Stay Rod.

VERTICAL AND TRANSVERSE SECTIONS OF EIGHT HORSE-POWER PORTABLE ENGINE.

CONSTRUCTED BY THE READING IRONWORKS, LIMITED.

boiling point. The travelling wheels and fore carriage are of wrought iron; the hind axle is cranked under the fire box, the weight being taken on the bottom, which prevents the fire box from being strained and joints rendered leaky. The main bearing brackets have a large area of base, so that the strain is well distributed; and the bearings, eccentric straps, pump plunger, valve, and seats are made of best gun metal.

STEAM ROAD ROLLER.

Steam Road Rollers are of much service in road making or repairing, and effect a considerable saving on the road repairs, as the road metal is thoroughly and effectually pressed into the roadway, giving a hard and smooth surface for the traffic. A layer of metal is laid down and the roller passes over it two or three times. Sand well watered is then sprinkled over the surface and again rolled. The mechanism is somewhat similar to the road locomotive, the rollers taking the place of the wheels. Where four rollers are used these are of equal widths, and are sometimes arranged so that the two hind rollers act as drivers and the two in front as steering rollers, the latter rolling on the space left uncovered by the driving rollers. The weights of the rollers vary with width covered, such as from 8 to 15 tons.

The Road Roller manufactured by Aveling and Porter of Rochester weighs 15 tons, and has four broad wheels or rollers. The front pair, 5 feet in diameter, act as driving wheels; the hind pair, 4 feet 9 inches in diameter, form as it were one broad roller, and slightly overlap the tracks of the front pair. The rollers cover a total width of 6 feet. The mounting of the hind rollers is so arranged as to leave the fore wheels free to adjust themselves to the turns or inequalities of a road. The arrangement of the cylinder and gearing is the same as that of the firm's ordinary traction engine. Two men attend the machine: one acting as steersman, the other, the driver, stands on the opposite side of the engine, and feeds the fuel by a side door in the fire box.

THE MACHINERY OF THE INMAN LINER "CITY OF NEW YORK" AND "CITY OF PARIS."

On our large folding plate we give a view of one set of the triple-expansion engines of the twin-screw steamer *City of New York*, built and engined by Messrs. James & George Thomson, Clydebank, to the order of the Inman and International Steamship Company. The many novel features of the hull are accompanied by almost as many novelties in the machinery. The adoption of the principle of twin-screws has been almost compulsory in this case, as it would be very difficult and probably very imprudent to construct single-screw engines having the enormous power that these combined twin-screw engines are intended to exert. The great advantage of the duplication of all parts is too obvious to be dwelt upon here, excepting to state that with only one of the engines running sufficient power would be developed to propel the vessel at about fifteen knots per hour. To indicate how the dimensions and power of the engines of the *City of New York* compare with those of the principal merchant single-screw steamers afloat, we give on page 770 a table compiled partly from a paper read by Mr. W. John, at the Liverpool meeting of the Institute of Naval Architects last year, and partly from the records of the trials of the steamers.

It will readily be seen that the power to be developed in the *City of New York* (20,000 indicated horse-power) is considerably in excess of that in the other steamers, and to have fitted a single set of engines, even supposing it had been advisable from every other standpoint, would have been a very questionable step to take. The view we give is of the port engine. The two engines are separated by a longitudinal bulkhead reaching up to the main deck, communication being established by a sliding door, worked by a rack and pinion from above in case of need.

Many of the features which are common to war-ship machinery have been introduced into the design of these engines in order partly to save weight and in consideration of the high piston speed. The engines are built upon a very solid structure in the ship, but have, in addition, a cast-steel bedplate. This bedplate is formed in three parts, each part weighing about sixteen tons. The columns are also of cast steel and are of the "split type." The condensers, which usually form part of the main engine structure, are made, as in war-ships, of brass, and are quite independent. The cylinders and their covers are cast iron, but the pistons are of cast steel of the dished type. The crankshafts are built of steel; the thrust, tunnel, and propeller shafts are also of steel. The crankshaft is 20¼ inches in diameter at the journal, and 21 inches at the pin; the tunnel shafting is 19¼ inches, and the propeller shafting 20¼ inches. The piston-rods and all the principal moving parts are of ingot steel. The piston-rods have tail-rods, and are attached to the pistons by flanged connections.

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*This description applies equally to "The City of Paris," the twin ship of "The City of New York."

The high, intermediate, and low-pressure cylinders are 45 inches, 71 inches, and 113 inches in diameter respectively, the stroke being 60 inches. All the valves are piston valves, being one on the high, two on the intermediate, and four on the low-pressure cylinders. The adoption of the four sets of piston valves for the low-pressure cylinder is unique, and is necessitated by the large port area in this cylinder, and to avoid the strains due to the great overhang which would be caused by the adoption of two sets only. The valve gear is of the ordinary eccentric type, the eccentric straps being of cast steel lined with white metal. The equilibrium valve, which controls the inlet of steam, is worked by an independent engine which can be connected to the Dunlop governor. The adoption of this engine renders the handling of the main engine very much easier.

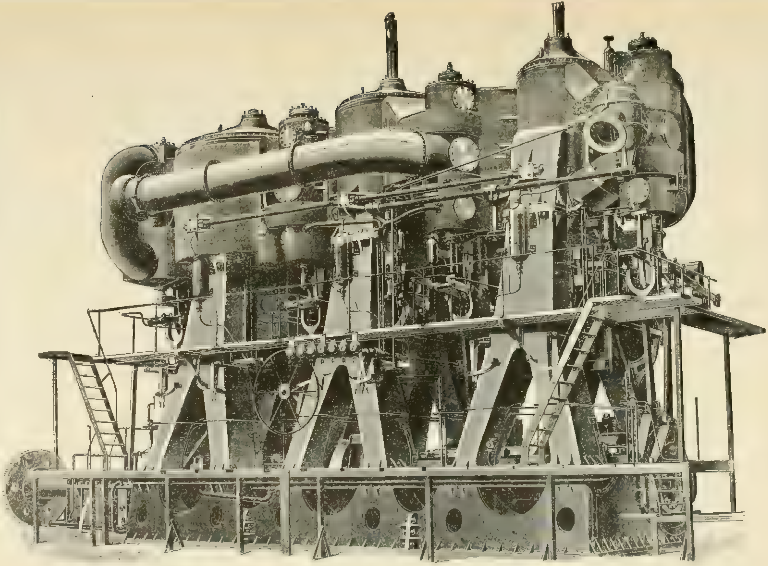
The turning engine is of a new type, being simply a hydraulic ram working by a pawl on a ratchet wheel. This ram is vertical, and takes up very little space; but is at the same time very powerful.

In addition to the usual draining from the jackets and casings, which is collected in the hot-well, there is a continuous flow through the casings from the high-pressure to the intermediate pressure casings, and from the intermediate pressure to the low-pressure casing. In the latter casing the drainage passes into the low-pressure cylinder in the form of vapor, there doing work, and finally passing into the condenser. By this means any accumulation of water is prevented in the casings when the engines are running, and the glands are always dry.

The air pumps are the only auxiliaries driven from the main engine. There are two of them to each engine, of the ordinary vertical type, and they are worked by levers off the high-pressure and low-pressure crossheads. A small oil pump is also driven off the main engines. It is for keeping the crank-pits clear of oil, which is forced into the stern tubes.

The boilers are fed by Worthington vertical pumps, four in number, associated with Gilmor's feed heater. These during the trial proved satisfactory, and in this connection it may not be uninteresting to indicate briefly their system. Each pump has two 12-inch steam cylinders, and 28½-inch double-acting water plungers, with a 10-inch stroke. There are two pumps in each engine-room. Of these one supplies the feed heater with water at the temperature of the hot well. This water has its temperature raised in the feed heater by live steam from the boiler to nearly the boiler temperature, and the second pump delivers this heated feed water at a slightly increased pressure to the boiler. There is no advantage on the score of economy; but in so far as the feed water is introduced at boiler temperature there is complete absence of any possibility of strain due to irregular cooling of the boiler plates. The heater can be thrown out at any time and only one pump used, and as the capacity of each pump is sufficient of itself for boiler feeding, the other may be looked upon as an alternative in case of breakdown. In the ordinary arrangement, the first pump, which delivers from the hot-well into the feed heater, is controlled by a float in the tank, so that it will be impossible either to have overflow or an insufficient quantity in the hot-well. As all the water passing through the feed heater is at a high pressure, all impurities in the water are deposited in the latter, from which they are occasionally discharged by means of a blow-off, and since the heater itself is in no way cramped or confined by large tubes its cleaning becomes a very easy matter. Indeed it is completely done by blowing off at regular intervals.

There are two fire and bilge pumps in each engine-room for general ship purposes. These are also so arranged that they can be used as feed pumps in the event of the main getting out of order, and they are connected to the double-bottom system of piping, and are available for pumping the compartments between the bottoms should the circulating pumps be in use for other purposes. The water is circulated through each of the main condensers by two sets



TRIPLE-EXPANSION ENGINES OF THE INMAN STEAMERS "CITY OF NEW YORK" AND "CITY OF PARIS." See Page 766

CONSTRUCTED BY MESSRS. J. & G. THOMSON, ENGINEERS AND SHIPBUILDERS, GLASGOW.

of 15 inch-centrifugal pumps, either of which is more than capable of doing all the work required. There are fresh-water condensers in each engine-room, which have their own feeding and circulating pumps automatically worked. All these pumps are of the Worthington type.

The hydraulic installation of the ship, which is the most extensive fitted on shipboard, has its pumping engines—two in number—in the engine-room. These engines are of the compound surface-condensing type of Messrs. Brown, now so well known in connection with hydraulic ship plant. These engines work seven hoists, nine derricks, two warping ends, a windlass, and two warping capstans aft on the promenade deck.

The steel boilers which supply the steam are nine in number, and are equally divided in three water-tight compartments. They are built of steel, the shell plates being $1\frac{9}{32}$ inches in thickness. The diameter of each boiler is 15 feet 6 inches, the length 19 feet and the working pressure is 150 pounds to the square inch. The boilers are double-ended, and have each six furnaces, the mean diameter being 3 feet 11 inches. The tubes are 7 feet 6 inches long, 2⅜ inches in diameter, and in each boiler there are 1,056 tubes, or 9,504 in the nine boilers. The total heating surface 50,040 square feet. The furnaces on each end have a common combustion chamber. Each boiler weighs 74 tons.

The boilers are worked on what is known as the closed stokehold system. This is the first ship for the Atlantic passenger trade that has been worked on this system, and it necessarily introduces many novelties. There are no air hatches excepting those through which the fans draw down the air supply. The fans for supplying air to the furnaces are twelve in number, and are each 66 inches in diameter. They are the result of very exhaustive experiments. The application of forced draught has become so general that the design of the engines has become equal in importance with the engine for propelling the ship. The experience which the Messrs. Thomson have gained during the past few years in constructing high-speed war-ships fitted with forced draught has enabled them to design a fan and engine that will work with great efficiency and comparatively no attention.

It may be added that during the construction of the machinery, Mr. J. S. Doran, Superintending Engineer of the Inman Company, acted as inspector, discharging duties, ordinarily difficult and trying, in such a way as to merit and secure the confidence of the Inman Company, and the acquiescence by the Messrs. Thomson in all his proposals.

HULLS AND ENGINES OF OCEAN STEAMERS.

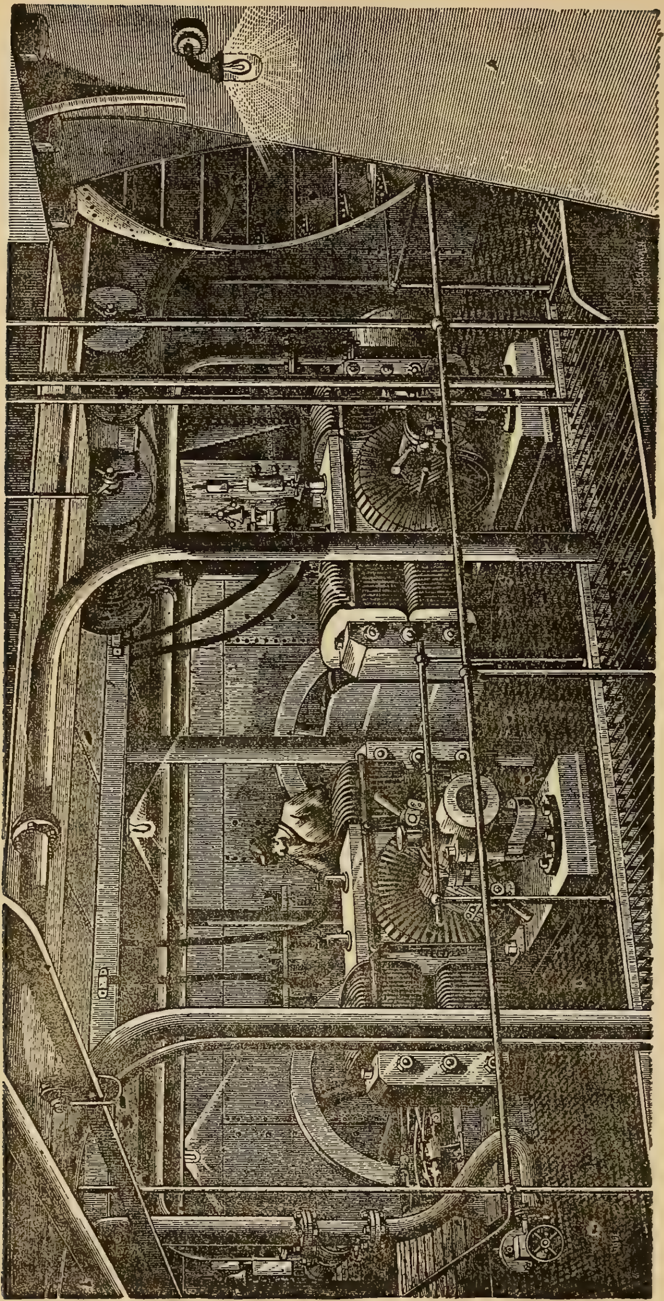
NAME.	Vessel's Dimension.						Engines	Engine Cylinders.					Boilers.		
	Length.		Breadth.		Moulded Draught.		Indicated Horse-Power.	Diameters.			Stroke.		Heating Surface.	Area Firegrate.	Working Pressure.
	ft.	in.	ft.	in.	ft.	in.					ft.	in.	in sq. ft.	in sq.ft.	lb.
S. S. City of Rome......	542	6	52	0	21	5½	11,890	$\frac{3}{46\text{ in.}}$	$\frac{3}{86\text{ in.}}$		6	0	29,286	1398	90
" Normandie.........	459	4	49	11	19	9¾	6,959	$\frac{3}{35\frac{7}{16}\text{ in.}}$	$\frac{3}{74\frac{7}{8}\text{ in.}}$		5	7	21,404	756	85
" Arizona.............	450	0	45	1½	18	9	6,300	$\frac{1}{62\text{ in.}}$	$\frac{2}{90\text{ in.}}$		5	6	....	......	90
" Orient................	445	0	46	0	21	4½	5,433	$\frac{1}{60\text{ in.}}$	$\frac{2}{85\text{ in.}}$		5	0	....	......	75
" Stirling Castle.....	420	0	50	9	22	3	8,396	$\frac{1}{62\text{ in.}}$	$\frac{2}{90\text{ in.}}$		5	6	21,161	787	100
" Elbe....................	420	0	44	9	20	0	5,665	$\frac{1}{60\text{ in.}}$	$\frac{2}{85\text{ in.}}$		5	0			
" Umbria & Etruria	500	0	57	0	22	6	14,321	$\frac{1}{71\text{ in.}}$	$\frac{2}{105\text{ in.}}$		6	0	38,817	1606	110
" Aurania.............	470	0	57	0	20	0	8,500	$\frac{1}{68\text{ in.}}$	$\frac{2}{91\text{ in.}}$		6	0	23,284	1001	90
" America.............	432	0	51	0	26	0	7,354	$\frac{1}{63\text{ in.}}$	$\frac{2}{91\text{ in.}}$		5	6	22,750	882	95
" Servia	515	0	52	0	23	3½	10,300	$\frac{1}{72\text{ in.}}$	$\frac{2}{100\text{ in.}}$		6	6	27,483	1014	90
" Alaska	500	0	50	0	21	0	10,500	$\frac{1}{68\text{ in.}}$	$\frac{2}{100\text{ in.}}$		6	0	....	......	100
" Ems.....................	430	0	46	10	20	7½	7,251	$\frac{1}{62\text{ in.}}$	$\frac{2}{86\text{ in.}}$		5	0	19,700	780	100
" Aller....................	438	0	48	0	21	0	7,974	$\frac{1}{44\text{ in.}}$	$\frac{1}{70\text{ in.}}$	$\frac{1}{100\text{ in.}}$	6	0	22,630	799	150
" Ormuz	465	6	52	1½	....		9,000	$\frac{1}{46\text{ in.}}$	$\frac{1}{73\text{ in.}}$	$\frac{1}{112\text{ in.}}$	6	0	26,000	850	150
" Lahn....................	448	5	49	0	....		9,500	$\frac{2}{32\frac{1}{2}\text{ in.}}$	$\frac{1}{68\text{ in.}}$	$\frac{2}{85\text{ in.}}$	6	0	....	......	150
" City of New York	560	0	63	3	25	0	20,000	$\frac{2}{45\text{ in.}}$	$\frac{2}{71\text{ in.}}$	$\frac{2}{113\text{ in.}}$	5	0	50,265	1293	150
" City of Paris.......	"		"		"		"	"	"	"	"		"	"	"
" Teutonic............	582	0	57	6	23	0	17,000	$\frac{2}{43\text{ in.}}$	$\frac{2}{68\text{ in.}}$	$\frac{2}{110\text{ in.}}$	"		45,000	1163	180
" Majestic.............	"		"		"		"	"	"	"	"		"	"	"

THE WHITE STAR STEAMERS "TEUTONIC" AND "MAJESTIC."

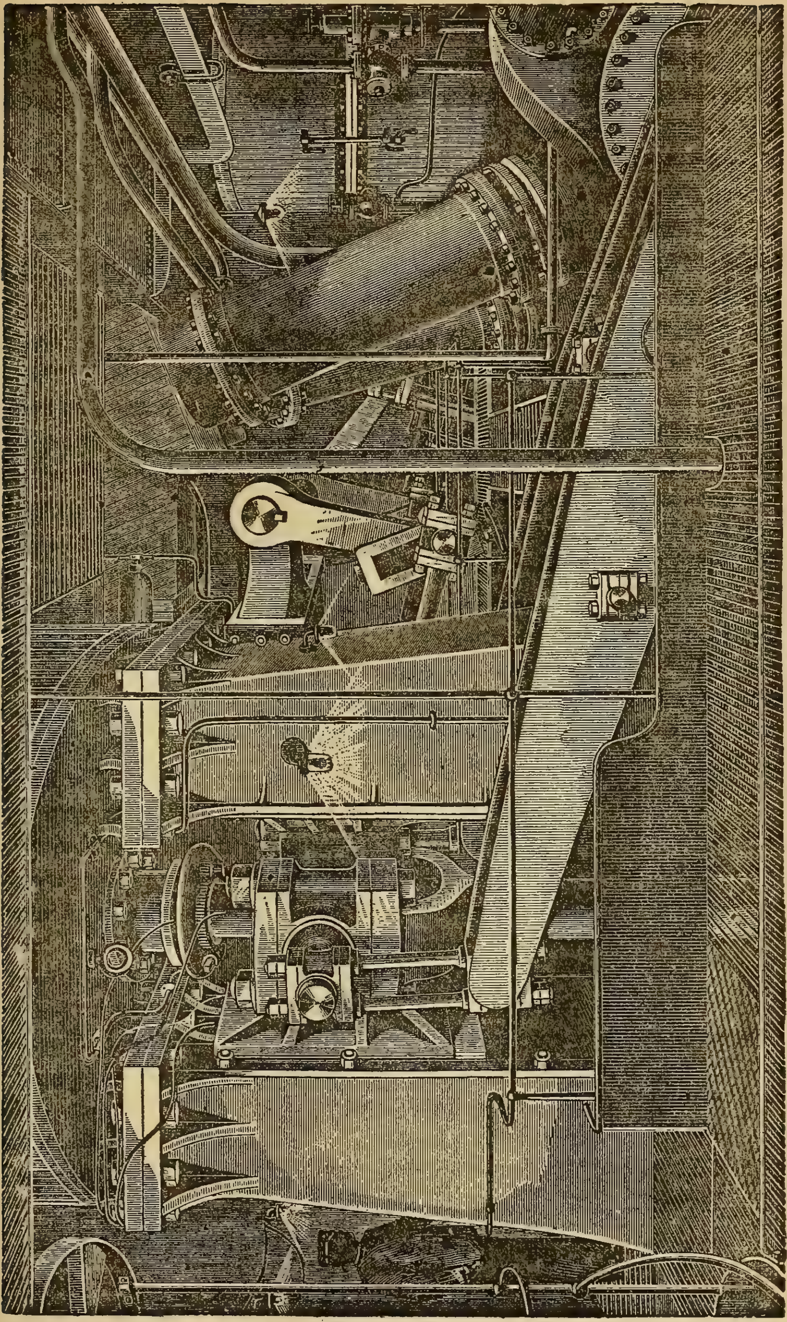
THESE two great steamships are twins, and differ only in name, and are at this writing, 1891 (if we except one or two iron clads), the largest ships in the world.

Anything approaching a description of the vessel and her machinery is beyond our purpose, because that would take a volume in itself.

The first proposal for establishing a regular steam service between New York and England was in 1836, when the *Savannah* and the *Royal William* came to life. Shortly after, the *Great Western*, the *Sirius*, the *British Queen*, the *President*, and the *Great Britain* were started, but were considered a commercial failure. The steamers named had all been withdrawn or lost, when Mr. Samuel Cunard established a line of (paddle) steamships with the aid of an English Government subsidy of $700,000 a year. The arrangement was a success, and this company in 1856 launched the magnificent *Persia*, and subsequently the *Scotia*, 3,300 and 3,870 tons burthen, with accommodations for 250 and 275 cabin passengers respectively. The length of the latter was 379 feet, breadth 48, making the run from port to port (New York to Liverpool) in eight days and twenty-two hours; this was in 1862. Her engines indicated 4,500 horse-power. She was the last of the great paddle-steamers. It would be foreign to our present purpose to give any approach to detail in an account of the rise and progress of the Atlantic fast steamers. It will suffice to say, that the paddle-steamers were surpassed by such ships as the *Russia*, *Gallia*, *Alaska*, *America*, *Servia*, *Aurania*, *Umbria*, *Etruria*, *City of Berlin*, *City of Paris*, and *City of New York*, and the *Teutonic* and *Majestic*. The *Teutonic* has a record, August 5, 1890, of making passage from Queenstown to New York in 5 days 19 hours; the *Majestic* has a record, September 5, 1890, of making passage from Queenstown to New York in 5 days 21 hours; these two ships are constructed on an absolutely new system, the joints are treble,



Starboard Electrical Room—Looking Aft.



Starboard Engines, Middle Platform.—Looking Forward.

quadruple, and in some plates quadruple riveted; the hulls are cut into water-tight compartments, and all the doors can be closed from the flying deck by pulling small wire-rope lines, which release hooks holding the doors up. The steering gear is elaborately protected so as to secure immunity from breakdowns.

One contrast of construction may be stated: The old *Persia* of thirty years ago had not a plate in her hull more than six feet long, the normal width being two feet; the skin-plates of the *Majestic* and the *Teutonic* are 24 feet long and 3 feet wide.

The *Teutonic* and *Majestic* are propelled by twin-screw triple expansion engines, indicating each 17,000 horse-power. The cylinders are 43 in. + 68 in. + 110 in. × 60 in.; the high-pressure cylinders stand next the boiler-rooms. The engine-rooms are 50 feet long; all the cylinders have piston valves. The valve gear is the Stephenson shifting-link type.

The screw shafts are placed so close together that the screws overlap 5 feet 6 inches. The engines make from 79 to 82 revolutions when driven at full speed. Steam is supplied by twelve double-ended and four single-ended boilers, heated by 84 furnaces; the pressure is 180 pounds; the weight of steam to be condensed may be averaged at 120 tons per hour. When the ships cross the Atlantic they move at a speed of 2,000 feet per minute.

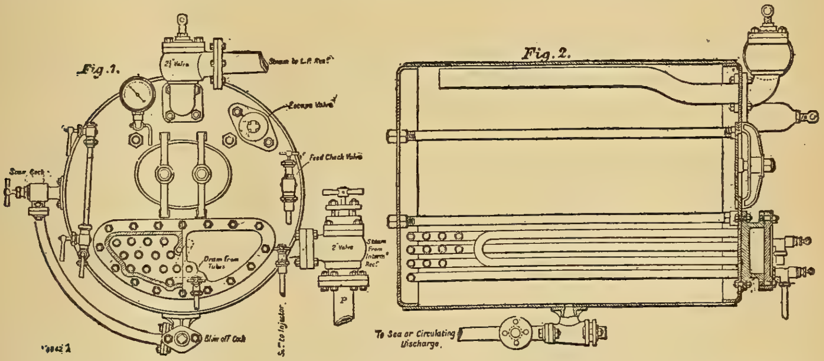
They carry four electric-lighting engines in two rooms, two in each; each dynamo is capable of supplying 400 lamps.

In these great ships everything has been done that art and science can accomplish to render the ships beautiful, luxurious, and safe; they are built under British Admiralty superintendence, and especially constructed for service as mercantile armed cruisers, and they are the first merchant steamers so specially constructed.

EVAPORATOR FOR TRIPLE COMPOUND ENGINES.

We illustrate an arrangement of evaporator and auxiliary feed boiler for triple compound engines made by Messrs. G. and J. Weir, of Holm Foundry, Cathcart, Glasgow. Steam is taken from the intermediate receiver, and passes to the tubes shown. Sea water is admitted to the interior of the cylindrical shell, and is there evaporated by the steam in the tubes. The resultant steam from the evaporation of the salt water is taken to the low-pressure receiver of the engine, and follows the usual course.

It is claimed that by the adoption of this apparatus the cost of production is one-third of the cost that would ensue were the ordinary practice followed. In order to prevent priming the steam space is ample in proportion to the heating surface, and in order that the whole of the latter may be equally efficient the outlet ends of the tubes are contracted, and the condensed water is drawn off by a tube, returning through the evaporator. In practice the tubes may be kept clean by blowing the brine out entirely and admitting cold water, which breaks off the scale, or the tubes may be scaled occasionally in the usual way, a man-hole door being provided as shown. If very dirty the tubes can be removed, both ends being exposed in the plate, as shown; they all come out together, the operation taking but a few minutes, as the tube-plate joints are faced.



EVAPORATOR FOR TRIPLE-EXPANSION ENGINES OF THE "CITY OF NEW YORK" AND "CITY OF PARIS," CONSTRUCTED BY MESSRS. G. & J. WEIR, ENGINEERS, GLASGOW.

DETAILS OF THE ACCIDENT WHICH OVERTOOK THE "CITY OF PARIS," IN APRIL, 1890.

LONDON, April 19.—No one has yet given a satisfactory explanation as to the cause of the recent disaster on the "City of Paris." *The Engineer*, in its current issue, contains an illustrated article by an expert who was permitted to inspect the vessel. This writer says:

"We examined the engine-room carefully before anything had been removed. The result of our examination was to show that everything that could be broken had been broken; what could not be broken was bent, twisted or distorted. Nothing so complete in the way of a breakdown has before been seen. The explosion of a great shell might work such havoc in an ironclad.

"Descending to the crank-platform, crawling under and climbing over a heap of fragments, we find some curious things. The top cylinder cover seems to be at the bottom of everything. The A frames have apparently disappeared bodily. The connecting-rod is still coupled to the crank-pin. The big end is intact, but the rod, about 14 inches in diameter in the middle, is bent. The piston-rod and cross-head are still coupled to the connecting-rod and lie folded back along the tail-rod, which is bent like a bit of wire, nearly in a semicircle.

"One side of the condenser has been torn out. The tubes are all displaced and a good many of them flattened. The air-pump levers are literally rolled up like bits of ribbon. On the side of a part of the cylinder is a great crack, but the metal still holds together in a way to demonstrate toughness in no ordinary degree.

"But the ruin is not confined to the engine-room. The great screw-shaft, 21 inches in diameter and over 100 feet long, has been ripped up out of its bearings from one end of the screw-tunnel to the other, and then dropped back again. All the cap-bolts are smashed. A great rent is torn in the bulkhead. Where the shaft passed through it the half-inch steel plate has been bent and buckled like a bit of paper.

"The smashing of the condenser was followed by an enormous rush of water into the engine-room. The condenser lies low in the ship, considerably under the winter-line. It is supplied by Gwynne's centrifugal pumps, drawing water through a copper pipe nearly 2 feet in diameter. The pumps and condenser were wrecked. The water, of course, rushed like a cataract through the broken pipes. Two holes were made in the bulkhead between the engine-rooms.

"The engineers did all they could to stop these holes, but they were ultimately driven out of the port engine-room by the rising water. The screw-shaft was ripped up out of its bearings from end to end. Then it dropped again, but in lifting it tore up the after bulkhead and left a large aperture through which the water rushed, filling the dynamo-room and screw-alley. Not a drop of water got into the boiler-room. The rush of steam into the engine-room was for the moment tremendous, but the engineers dashed into the engine-room and screwed down the stop-valve with commendable courage and promptitude.

"As to the cause of the accident experts are satisfied that something in the engine did not give way first, but that the sequence of events was as follows:

"The brass-liner on the tailshaft burst;

"Then the lignum-vitæ strips were torn out, bringing metal to metal;

"Then the tailshaft ground away the liner on the stern-bracket;

"Then the steel-shaft ground away itself, and the bracket and shaft dropped;

"Then the continual bending action which took place resulted in the shaft breaking just where it came out of the steam-tube."

It is now (May, 1890) announced that it will take nine months to put the great steamship into first-class condition, so that we need not expect to see her making her accustomed trips till 1891. *Moral:* It seems that the climax of size and speed in ocean steamships has been reached for the present.

The discovery of the broken propeller shaft of the *City of Paris* has ended all speculations as to the true cause of the accident to her starboard engine, and affords a convincing proof of the necessity in all steamers for an efficient governor that will shut off the steam immediately the load on the engines is relieved by accident or any other cause.

ENGINE-DRIVERS.

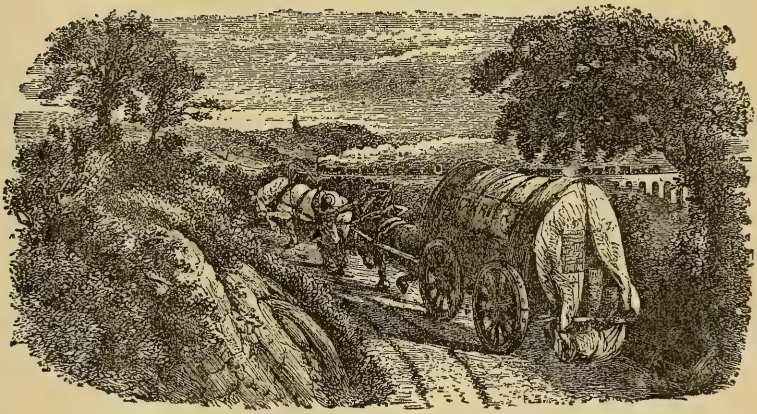
THEIR RESPONSIBLE DUTIES AND THEIR TRAINING FOR THEM.

Engine-drivers, says our London editor (September, 1888), are very little known as a class, though the duties they discharge are public and very responsible. The fact is that the engine-driver, who must not only be skilled in the technicalities of his business, but must possess intellectual and moral qualities of a high order, has never risen above the rank of the artisan; nor does he pretend to rise above it; and yet he must be almost as capable and as dutiful as the captain of a ship or the commander of a regiment. This workman, whose cool judgment and unceasing watchfulness are more serviceable than any mere manual skill he may possess, is worth attention.

Engine-drivers are neither born nor made: they grow. You cannot apprentice a boy to engine-driving. Engine-driving, however, is the goal of the ambition of most boys who begin their working life in a locomotive shed. From being a kind of "devil" to everybody, the boy gradually becomes a "cleaner." Supplied with a bundle of cotton-waste, he rubs over the working parts of the engine, and thus acquires a knowledge of its construction. At this work he may be kept four or five years. If he is fit for nothing better, he remains at it all his life. But if he is steady, quick and handy, he is sure to attract the notice of the foreman; and the foreman occasionally calls on him to fire an engine, or haply to run one out of or into the shed. It is a proud day for him when he first steps on the foot-plate of an engine, charged to drive it a few yards—out into a siding, perhaps, or up to the train to which it is to be attached. From this point everything depends on himself. By-and-by he obtains an appointment as fireman, most likely on an engine which is never engaged in hazardous work. Perhaps it is a pug-engine doing yard or station duty, and never permitted on the main line or principal sidings. Here the growing engine-driver learns something of the weight of trains, of the regular supply of steam, of the relation between the steam-pressure and the work to be done, of economizing coal, and generally of the management and working of an engine. Then a vacancy occurs among the firemen on the regular goods traffic, and "the most steady and promising young hand in the shed" is promoted. He now obtains a knowledge of "the road," learns to read the signals as well as the other multitudinous signs by which the experienced engine-driver feels his way along, and, of course, becomes proficient in the art of keeping up the motive power to the point needed by the driver. He may even now be working merely on a branch or on a slow goods train; but he is decidedly getting on. He fathoms the mysteries of shunting. Billiard players will understand what we mean when we say that in shunting "strength" is everything. The engine, like a cue, propels the trucks with just sufficient force, and no more, to land them at the desired spot, the engine itself pulling up as soon as the momentum has been applied. Marvellous stories are told of great shunters—men of genius in their way. There was Joe ——, on the Caledonian, who could shove his train up to and past a set of points, check his engine to give time for the points to be changed, then run on without having stopped, put on speed so as to overtake and get ahead of the still running trucks; and finally, passing over another set of points, bring up his engine just in time for it to receive a gentle tap on the other end from the trucks, which are now coupled on behind it instead of before. Our young fireman may never venture to attempt this feat; but at a very early period it is set before him as the sort of thing that can be done, though he may never hope to do it.

From goods fireman he is promoted to goods driver: an important move. He already knows the road, can read the signals, and gauge the weight of a train; but he has yet to learn how to keep time on a journey, how to regulate the brake so as not to waste power, how to utilize "straights" and descents, how to climb hills and go safely round curves. Goods trains not being greatly pressed for time, he has a margin to work upon, and after a few journeys his difficulties disappear. Not only can he work his train in perfect accordance with the system laid down, not only does he learn by heart the signals, points, gradients, and other features of the road, but he is able to detect weak spots in the permanent way. In such cases he scribbles a line on a piece of paper, and throws it out to the first platelayer he passes. That generally suffices; but if not, he makes a report to the chief engineer. He does not know what it is—ballast shifted, sleeper broken, chair defective, or rail given way; but he feels there is something wrong, and until it is put right he passes over the spot with such caution as to neutralize the danger. His phase as goods driver is one of the most important in his progress. But he has not yet done with stoking. His next step is as passenger fireman. His finer qualities, if he possesses them, are now coming into play. It is true he has simply to maintain the motive power for the service of the driver, but he is something better than the boy who blows the organ bellows. He is the driver's companion and helpmate; he is probably as competent as the driver himself; and he necessarily exercises a moral influence which, if strong, proves invaluable to both of them in cases of emergency. One might almost compare them to companion lighthouse-keepers. Should an accident occur, it is the fireman's duty to run forward with a danger flag, just as it is the rear guard's duty to run back and "protect" a following train. Then from passenger fireman he becomes passenger driver. But there is a great difference in passenger drivers. The one whose development we have traced is one of the best. Passing over his stages of employment on branch-lines, slow main-line trains, specials, and so on, we come to his final phase, as the driver of the great express—the Flying Dutchman, Scotchman, or Zulu, or the Wild Irishman, as the reader may choose to suppose.

What is his position now? Well, he is a man whose efficiency and character will, from any point of view, stand the severest tests. He is an expert, whose training has been of the most gradual, minute, and thorough description, who has climbed step by step to the top of the ladder, where his foothold is now as firm as if he were standing on the solid ground. His wages are (say) fifteen shillings a day; his working hours are fifty-six or fifty-seven a week; he is exposed to all sorts of weather—very peculiar weather it is, too, on the footplate of a locomotive, with your feet scorched by the heat while the bitter east wind freezes the moisture on your beard; and he is charged with the duty of taking (say) three hundred passengers from London to Exeter, or Glasgow, or Edinburgh, or Holyhead, within a certain time, at an average speed of fifty miles an hour. From the moment he starts to the moment he arrives he is under a constant strain. Not only are the peculiarities of the road, which he knows from experience, to be noticed, but every mile or two there is some official sign put up for him to read. Level crossings, points, tunnels, bridges, viaducts, stations, platelayers, gradients, curves—all these he must look out for. Consider the operation of climbing and descending a "summit," or descending and then climbing a "valley." At these times the driver's hand is never off the lever. In the course of a few miles he will perhaps make fifty imperceptible changes in the speed of the train—accelerating it or diminishing it so steadily that not a passenger notices what is being done. That is the perfection of engine-driving. That is the climax of the driver's skill, and he attains it coincidently with the full development of those qualities which he has unconsciously trained within himself, and which are all governed by an overmastering sense of duty.



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SUPPLEMENT

TO

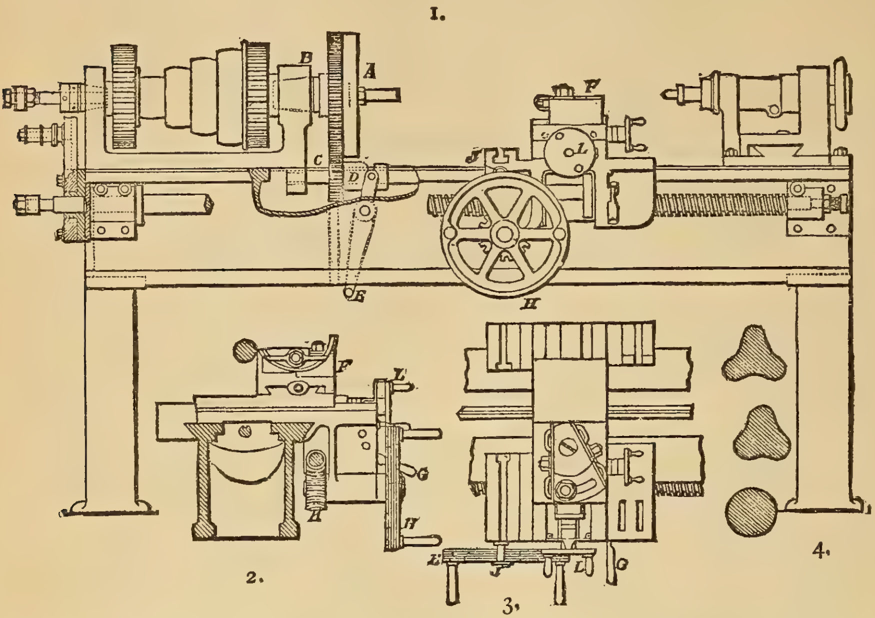
MODERN STEAM PRACTICE AND ENGINEERING.

MACHINE TOOLS.

THE progress in constructive engineering is always closely connected with the means of effecting improved work, and of these, machine tools form a most important feature. Although few radical changes have been made of late years, yet there have been many improvements in points of detail, and many of these will be found illustrated in this article.

Lathes.—A lathe designed by W. Silver Hall, of Nuneaton, presents several special points of interest. Its general arrangement, Fig. 1, is that of a screw-cutting lathe with centres 7 in. above the bed, which is 11 in. deep and 13 in. wide across the top. The leading screw is placed in front of the bed, is 2 in. in diameter, and has two threads to the inch. The form of thread adopted is similar in cross-section to the tooth of a spur wheel, thus affording ample wearing surface, while it is more easily engaged and disengaged than is the case with a thread of square section. There is nothing special about the driving headstock, except that the face-plate A has cast on its back a spur wheel B, gearing in the proportion of 3 to 1, into the pinion C on the shaft D, which extends the whole length of the lathe to the following headstock. C can be slid in or out of gear by the clutch fork and lever E. A mark stamped on C, corresponding with three marked positions on the face-plate, Fig. 1, ensures that they shall always be placed in gear in a certain definite relation to each other, and this is a matter of importance.

The saddle and slide rest are shown in Figs. 2, and 3. The cross slide has a very long bearing, and the wearing surfaces and screw are well protected from dirt and shavings, as is also the leading screw. The cutting tool for screw cutting is of peculiar form, being part of a steel ring carefully turned up to shape, and then cut asunder and hardened. It will be seen that it only requires to be ground straight across its end when requiring to be sharpened, and that the correct angle of thread is constantly preserved. Two of these tools, each clamped by a single nut and crossbar, are fixed in a V-shaped block F, forming the tool holder, which is pivoted on the top of the rest, and is capable of swivelling through an angle of 27½°. In the position Figs. 1 to 3, the right-hand, or screw-cutting tool, is in contact with the work to be chased, while that on the left hand is just clear. In the other position of the tool-holder, the flat edge of the left-hand tool is brought up, as would be required to top off the threads of a taper tap. The tools being adjusted just level with the top of the rest are always at the right height for their work, and another feature in this tool-holder, is that the correct rake of the tool is always given. Moreover, by adjusting the graduated handwheel L to any given position, the same distance of the tool point from the centre, and consequently the same diameter of work, is always ensured. For cutting a left-handed thread the tools must be turned end for end, a second tool-holder properly grooved to fit them in this new position being substituted, while for ordinary work a block with studs and crossbars, precisely like the top of an ordinary slide rest, can be put on instead of the swivelling tool-holder, in a few moments.

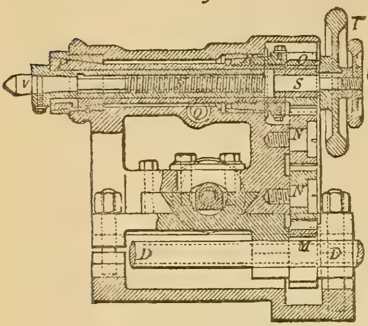


The leading screw is clamped or released by the handle G, which is very conveniently situated. The clamp nut has a long bearing and clasps both sides of the screw. For bringing back the saddle to its first position, after taking a cut the length of the screw, the handwheel H and wormwheel K, which has twenty-four teeth, are employed, the wormwheel and leading screw acting as rack and pinion, and as the wormwheel is of gun-metal and the screw has a very large wearing surface, this may be done without any injury to the screw. This wormwheel and handwheel also perform another important function. When the screw is not clamped, and the saddle is stationary on the bed-plate, the handwheel, which is graduated with twenty-four divisions, corresponding with the teeth on the wormwheel, will be seen slowly to revolve, bringing each division in turn opposite to the index J, Figs. 1 and 3. In these positions only can the leading screw be clamped, so by watching them the workman knows at once when to raise the handle G, without grinding the clamp nut over the surface of the screw until it will drop into position. Again, it is well known that to cut certain pitches, for example, eleven threads to the inch, it is necessary to clamp the screw at every second revolution, and if it is clamped at an intermediate revolution the thread will be split. The usual method of doing this is by watching for the coincidence of a chalk mark on the face-plate with another on the leading screw, but in the lathe in question this is provided for by a second graduated circle on the handwheel H, having only twelve divisions. There are also other circles divided into eight, six, and four parts, but these are very seldom required. By winding the screw L of the cross slide, back to its fullest extent, the slide rest can be slid off entirely, leaving the saddle, which is provided with suitable slots and bolt holes, clear for boring small cylinders, pedestals, or for other general or special work.

Many attempts have been made to contrive a satisfactory method for giving the relief, or backing-off, required in screw taps during the operation of chasing, so that they shall not require finishing by hand-filing, which after all can only relieve the tops of the threads, leaving the full bearing surface at the bottoms and sides. As the required relief is very slight, and demands to be accurately proportioned, these attempts have usually failed, owing to the difficulty of adjustment in the first instance, and of maintenance free from looseness and backlash afterwards. This is effected in Hall's lathe by the peculiar following or poppet headstock, Fig. 1, and in detail to a larger scale, Figs. 5, 6.

The shaft D, which is driven by the pinion C off the face-plate wheel B, and which makes three revolutions for every one of the lathe mandrel, imparts a similar triple revolution through the pinion M and the idlers N N to the pinion O, which is keyed on the tubular mandrel P. This mandrel revolves in adjustable conical bearings in the following headstock, but can be clamped when not required for use by a screw wedge at Q, much as in an ordinary headstock, and contains the ram R, which is propelled and withdrawn by the screw S and handwheel T, and clamped by the wheel-nut U. The nose of this ram is bored eccentrically, $\frac{1}{16}$ in. out of the centre, to receive the cone centre V. The mandrel P is caused to revolve, carrying with it R, S, T, U, and V, and a turning tool being applied to the latter it is turned up, of course truly concentric with P, and its position carefully marked O, Fig. 8. If now it is turned half round in its seat the point will be $\frac{1}{8}$ in. out of centre, and when revolving with the mandrel P will describe a circle $\frac{1}{4}$ in. in diameter, and its adjustment for any less eccentricity may be made with very great delicacy, being measured on a graduated circle 3 in. in circumference.

5.



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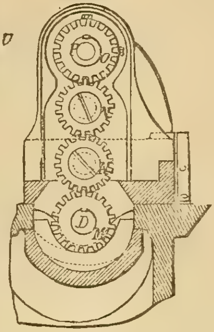
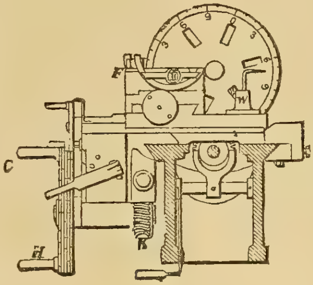


A rod or other article turned between centres will, consequently, approach to or recede from the cutting tool three times in each revolution, and at the following headstock end will receive the form of the upper diagram, Fig. 4. This eccentricity will decrease towards the driving headstock, as in the centre diagram, approaching nearer and nearer to the true circle. A tap chased on this principle will consequently have plenty of clearance, or relief, at the commencement, while the final cut is made by that portion of the tap which is nearly circular, and a very truly tapped nut is the result.

By a curious but not difficult calculation, the mark on the face-plate corresponding with the fullest side of the tap, which varies with the degree of eccentricity adopted, which we will suppose to be seven, as shown in Fig. 7, is found, and by bringing this number, which is repeated three times on the face-plate, opposite the point of the scriber W, which is set to the height of the lathe centre, three lines may be scribed on the shank of the tap before removing it from the lathe, giving the exact position of the cutting edges.

7.



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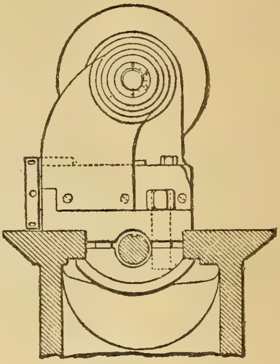


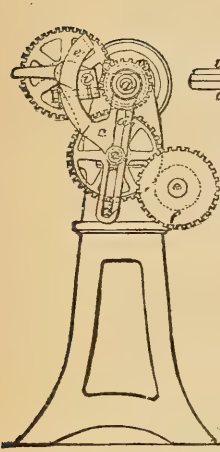
As the variation of radius from the true axis is alternately in excess of, and less than, the normal radius, and as it is necessary that the point of the tap should enter the same sized hole as if it were truly circular, it is necessary to set the following headstock as if for taper turning, for which purpose it is fitted with a cross slide and screw with graduated handwheel. This adjustment being very slight, does not interfere with the gearing of the pinion M and the first idler N, Figs. 5, 6, which at the commencement are set rather deep in gear.

By adopting a double instead of a treble ratio in the eccentric gear, an elliptic figure is obtained, and in this manner, and by varying the distance between the front and back centres, the blocks or moulds can be obtained in endless variety, and of any shape.

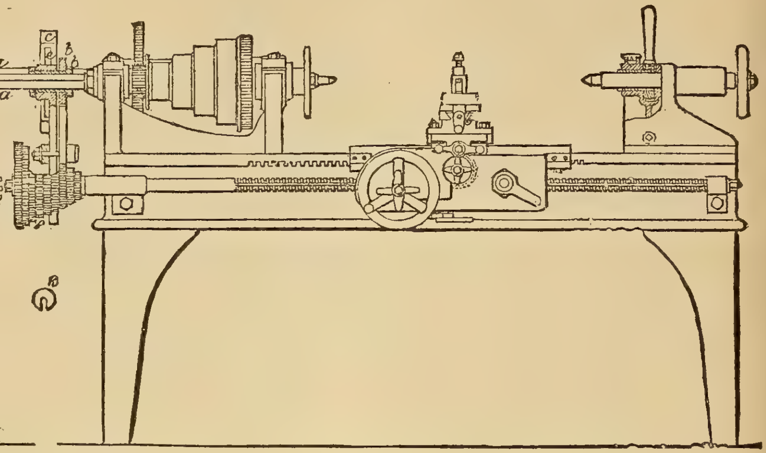
Figs. 9 to 11 are of a screw-cutting and turning-lathe, constructed by Ferris and Miles, of Philadelphia. It has been designed to afford a quick and convenient method of cutting screws of different pitches, and of changing from turning to screw-cutting, or the reverse.

The cone spindle *a* extends beyond the end of the lathe, and carries upon it two sliding pinions *b b* of different diameters, upon whose boss plays a double-slotted swing-arm *c*. This arm may carry by means of the straight slot *d* one or more intermediate wheels, which gear with either of the sliding pinions *b b*, and can be swung into gear with any wheel of the cone of gears *f* on the lead screw of the lathe. Also by means of the curved part with its slot *e*, the swing-arm may be fastened by its split-clamp *g* and pinch-bolt *h*, at any point of the index stud *i*.

9.



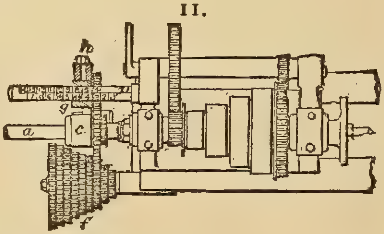
10.



The wheels of the cone *f*, are so calculated with reference to the sliding pinions upon the spindle, that sixteen or more different screw threads of the American standard may be cut by them, say from 1 or 2 an inch pitch up to 14 an inch. These figures are laid off and stamped as an index upon the index stud *i*.

Practically, therefore, the operator has only to set the split-clamp *g*, by its pinch-bolt *h*, at any desired figure of the index. The intermediate wheel will then gear with the proper wheel upon the lead screw to cut the pitch indicated by the index figure. The upper line *p* of figures in Fig. 11 shows the number in pinion, and the lower line *s* the number in spur.

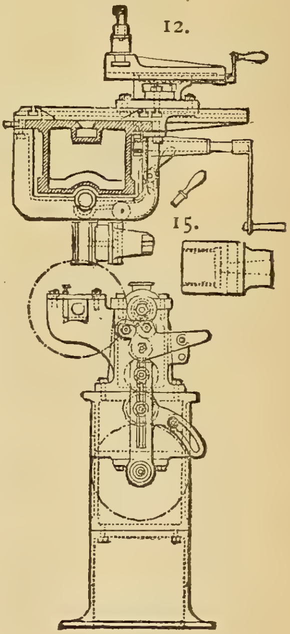
11.



Of the two lines of figures of the index, the one marked in spur is derived from the large sliding pinion *b*, the other line marked in pinion from the smaller. The change from one to the other is made instantly, by slightly slacking the screw stud, which clamps the intermediate wheel in the straight slot *d* of the swing-arm *c*, and changing the split-washer *k* from the inside of the arm to the outside, or the reverse, the intermediate wheel being moved just one gear face, as the split-washer *g* is of just that thickness.

The thread upon the lead screw is reserved for screw-cutting only, but by means of a keyway traversing its whole length, the screw is also made to serve as a driving shaft for a train of gears in the carriage, from which is derived the cross feed motion, and also, by means of the rack upon the bed, the longitudinal traverses for turning and surfacing. These are applied and released by single motions of convenient handles. It is to be observed that the index gives sixteen or more changes of traverse by the rack gearing for turning, and surfacing, and cross reversing, in addition to the sixteen or more changes by the lead screw for screw cutting. Therefore the operator has at his instant command a variation of thirty-two or more traverses, comprising all the screw threads in general use.

The sliding head spindle is fitted with a split conical bushing. This can be drawn into a conical seat by a nut and handle when it is wished to clamp the spindle which, by this means, is centred and held truly in line.


12.

15.

14.

The lathe by Richards and Atkinson, of Manchester, Figs. 12 to 17, has some features differing from ordinary practice. It is intended especially for performing repair work in wood-working and other factories, and is reduced to the most simple form, so as to cheapen its first cost, and present no complication which might hinder successful use in the hands of those not well skilled. The feeding and chasing screw are placed centrally under the frame, out of the way, and well protected from chips and dirt. The distance of the feed screw from the spindles is the same as though it were placed at the side of the frame, and the nut being under the centre of the saddle, the force of the screw falls equally on each side. The nut is engaged and disengaged by a pivoted bar, Figs. 13, 17. The cone pulleys are respectively 12 in., $9\frac{1}{2}$ in., 7 in., and 6 in. diameter, with a width of $2\frac{5}{8}$ in. on the face. The saddle is connected at the rear end, and considerably strengthened by a strong frame surrounding the main frame, Fig. 12; the latter frame is mounted on a strong box leg, 12 inches square, placed nearly under the gap, instead of at the end of the frame in the usual manner. The tool block is mounted on a swing plate, and can be moved to any point on the saddle, which is made with a plain flat top to accommodate boring, milling, or drilling appliances. The sliding head is arranged with a lateral adjustment for turning tapering pieces, and can be set 2 inches from the centre line. The gap piece is fitted at one end only, flat against the frame, and kept in place with accurately fitted dowel pins. The change wheels are so arranged that but a single one is changed in cutting screws from four to twenty threads to an inch. Fig. 16 is an end view of the gap piece, and Fig. 15 is a chuck to hold drilling tools.

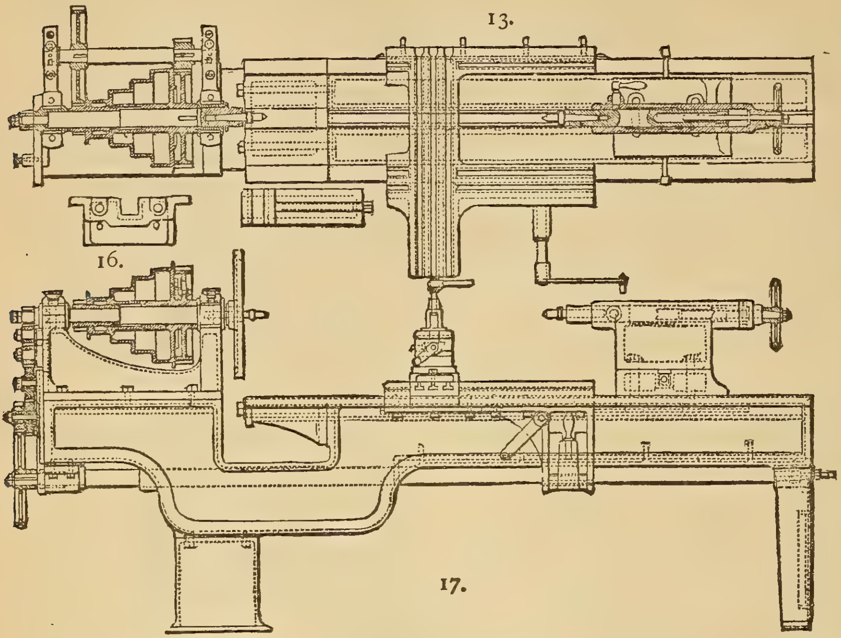
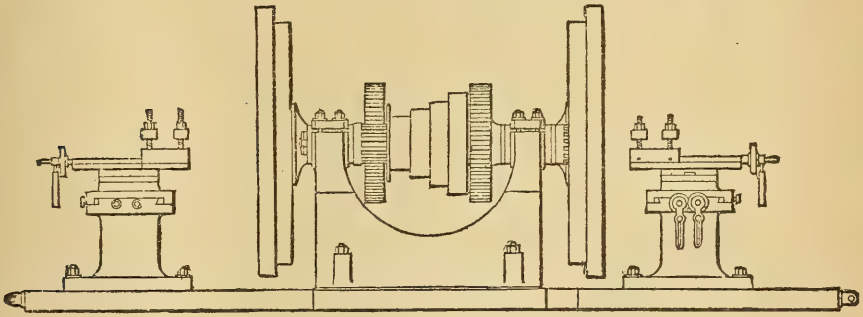


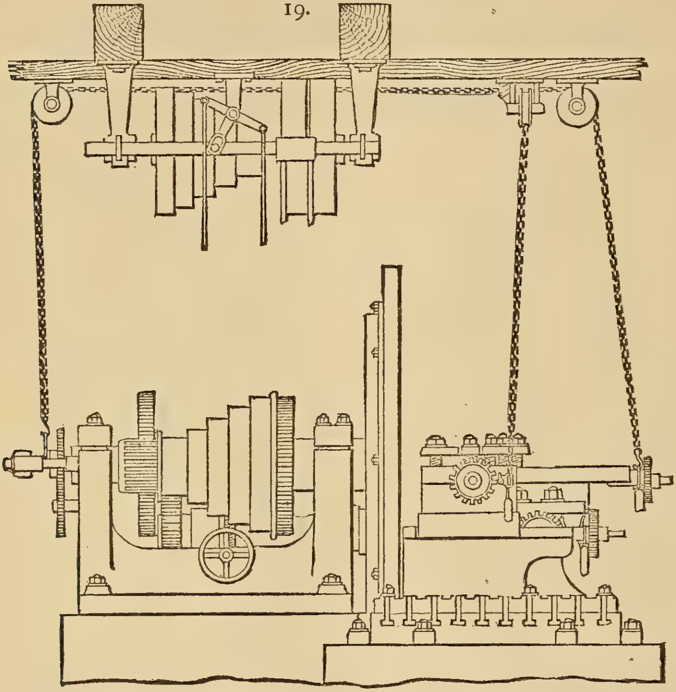
Fig. 18 is a double lathe for turning the tires of railway wheels, or executing any similar work. Two separate lathes are carried on one base plate, thus effecting a saving of space, and rendering the machine compact and self-contained; one man can attend to both lathes, as while one side of the lathe is working he can be engaged in fixing the work on the other side, or both sides can be working together. Both the rests are fitted with two compound tool-holders, each worked by separate screws, so that they can be adjusted quite independently of each other, thus allowing two cuts to be taken on the work at the same time. The lathes are made self-acting by the ordinary overhead gear. The total weight is about 20 tons, and it is arranged to turn up to 6 ft. diameter. The driving cones have each four speeds, the largest being 27 in. diameter, and the smallest 15 in. diameter, and arranged to take a strap 4 in. wide. It is treble-geared, thus giving a great amount of driving power. The spindle wheels are 2 ft. 6 in. diameter by 5 in. wide, and the face-plate is 5 ft. 6 in. diameter; all this gearing is $1\frac{5}{8}$ in. pitch. The journals in spindles are $6\frac{1}{2}$ in. diameter by 11 in. long, and made of Bessemer steel. The bushes are of the best gun-metal. The saddles for the compound rests are 7 ft. long, the screws in them are $1\frac{3}{4}$ in. diameter, and cut with a double thread to $\frac{1}{2}$ in. pitch. The compound screws are $1\frac{3}{8}$ in. diameter. The screws for adjusting the saddles are $2\frac{1}{2}$ inch diameter, and cut two threads an inch. The total length of base-plate is 18 ft. wide, and 6 in. deep.

18.



The facing-lathe, Figs. 19 to 21, by H. Hind and Son, of Nottingham, is a special tool designed to facilitate the turning, boring, and facing of fly-wheels, strap pulleys, and the like, which may run up to 12 ft. in diameter, and 18 in. in breadth. It consists of a massive headstock carrying a strong face-plate 8 ft. in diameter, bolted on a wrought-iron spindle 10 in. in diameter at the large bearing. The lathe is single, double, and treble-geared; the ordinary cone speeds are 5 in. broad, the large speed 2 ft. 8 in. in diameter on the spindle, and back gearing on an eccentric shaft; and has a third shaft and wheels running in an eccentric socket at the back of the headstock, on the end of which the pinion is keyed for gearing into the internal wheel bolted upon the back of the face-plate, this socket being thrown into gear with the back socket and face-plate wheel, by the worm and wormwheel moved by the handwheel in front of the headstock. There are three tool rests, each fitted with compound slides and swivel motion. The front rest is arranged with a broad holder for two tools, which will turn down the sides of a wheel rim, or the edges of drums, at the one operation, whilst at the back, or opposite side of the wheel more properly, the inverted tool and rest are placed for turning the faces of the fly-wheels or drums. This last rest is fitted with an additional slide moved by a steel runner working in a bracket, so that when the feed screw is traversing the tool across the face of the wheel the template moves the slides and the tool to its own curve, thereby turning the curve or rounding of wheel at one cut.

19.



The centre rest is for boring and facing the bosses of wheels, and is fitted as the other, with compound slides and swivel motion for facing and turning the boss, and for boring; one end of the cutter bar is held in the tool-holder, and the other end of the slide is steadied in a hole 3 in. in diameter and 18 in. in depth, bored in the spindle, by which means a boss 18 in. deep can be bored if required. The whole of the rests can be worked together or separately; they are mounted on a strong foundation 17 ft. 6 in. in length, and are readily adjustable in any direction. They are worked by a chain moving a weighted lever and catch, acting on the feed wheels in any position, the chain being worked from a disc wheel on the back shaft, and driven from the main spindle end. The weight of this lathe complete is 18 tons and 15 cwt.

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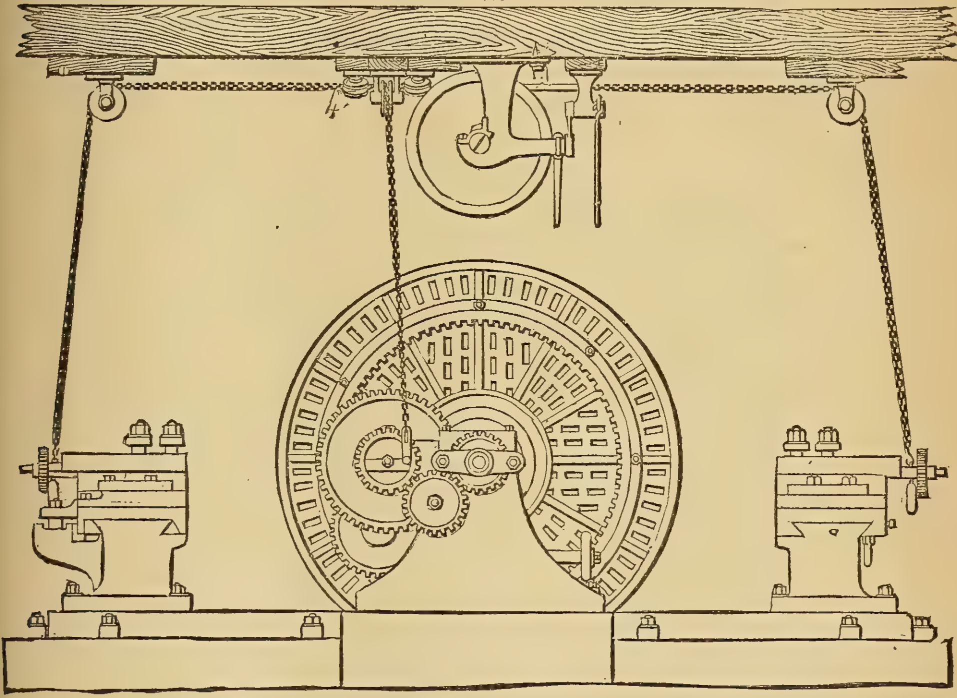

To avoid imperfection in the running spindles of lathes, or any lateral movement which might exist in the running bearings, there have been many attempts to construct lathes with still centres at both ends for the more accurate kinds of work. Such an arrangement would produce a true cylindrical rotation, but must at the same time involve mechanical complication to outweigh the object gained. It has besides been proved by practice that good fitting

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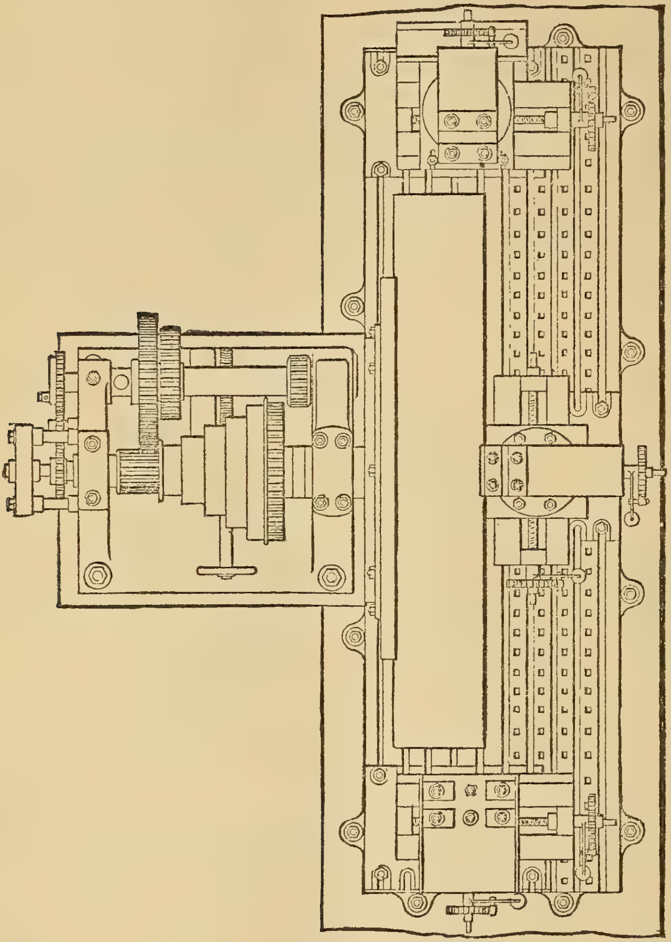

and good material for the bearings and spindles of lathes will ensure all the accuracy which ordinary work demands.

The cutting point in both turning and boring on a slide lathe is at the side of a piece, or nearly level with the lathe centres, and any movement of a carriage horizontally across the lathe affects the motion of the tool and the shape of the piece acted upon, directly to the extent of such deviation, so that parallel turning and boring depend mainly upon avoiding any cross movement or side play of a carriage. This, in both theory and practice, constitutes the greatest difference between flat top and track shears; the first is arranged especially to resist deviation in a vertical plane, which is of secondary importance, except in boring with a bar; the second is arranged to resist horizontal deviation, which in nine-tenths of the work done on lathes becomes an exact measure of the inaccuracy of the work performed.

A true movement of carriages is dependent upon the amount or wearing power of their bearing surface, how this surface is disposed in reference to the strain to be resisted, and the conditions under which the sliding surfaces move; that is, how kept in contact. The cutting strain which is to be mainly considered, falls usually at an angle of 30° to 40° downward toward the front from the centre of the lathe. To resist such strain a flat top shear presents no surface at right angles to the strain; the bearings are all oblique, and not only this, but all horizontal strain falls on one side of the shear only; for this reason flat top shears have to be made much heavier than would be required if the sum of their cross-section could be employed to resist transverse strain. This difficulty can, however, be mainly obviated by numerous cross girts, which will be found in most lathe frames having flat tops.

A carriage moving on angular ways always moves steadily and easily, without play in any direction until lifted from its bearing, which rarely happens, and its lifting is easily opposed by adjustable gibs. A carriage on a flat shear is apt to have play in a horizontal direction because of the freedom which must exist to secure easy movement. In the case of tracks, it may also be mentioned that the weight of a carriage acts as a constant force to hold it steady, while with a flat shear the weight of a carriage is in a sense opposed to the ways, and has no useful effect in steadying or guiding. The rigidity and steadiness of tool movement is notoriously in favour of triangular tracks, so much so that nearly all American machine tool-makers construct lathes in this manner, although it adds no inconsiderable cost in fitting.

Tapping, which is the converse of screwing, is usually done by substituting a tap for the dies in a screwing machine; but where the hole is small, or does not pass through the work, there are objections to this plan. There is an ingenious form of tapping machine used by gunmakers and sewing-machine manufacturers for that kind of work. One of these machines is shown in Fig. 22. The tap is clamped in a chuck on the end of a spindle, which runs in bearings in a small headstock, and has a certain amount of end movement allowed it; two pulleys run loose, in opposite directions, on the spindle, and the one at the front of the headstock revolves faster than the other. The work to be tapped is placed in a small rest, or holder, at the end of a bar that slides through a loose headstock. When the hole is to be bored, the work is pressed slightly against the end of the tap; this moves the spindle endways, and causes a lug to come in contact with the back pulley, which makes the tap revolve in the proper direction for cutting. The action of

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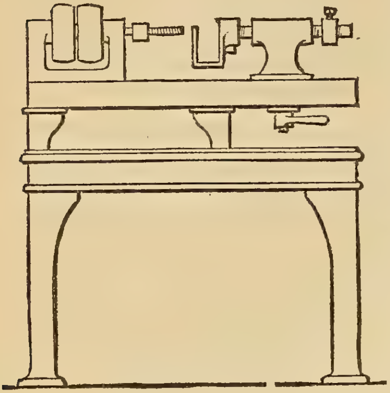

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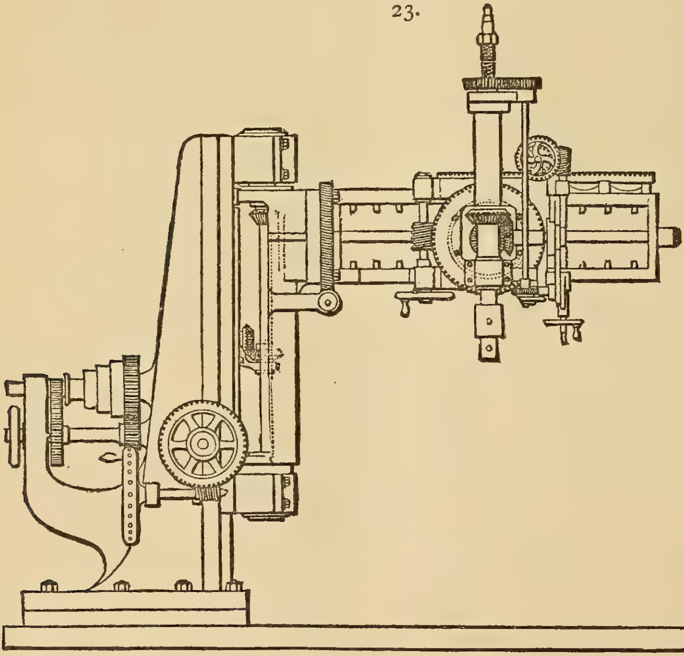
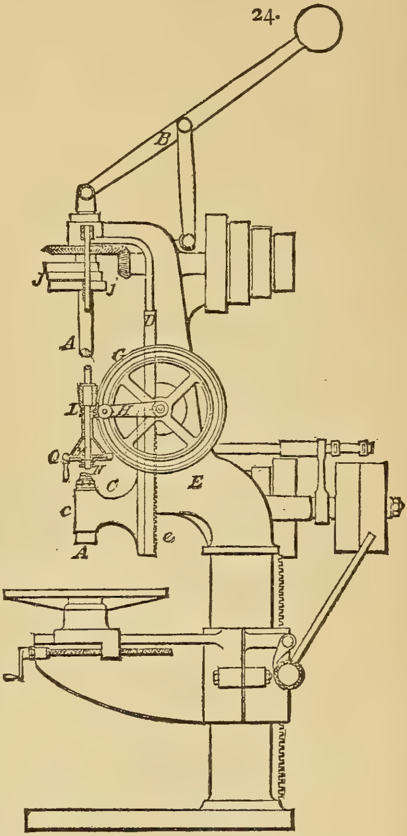


the tap draws the work forward until an adjustable collar on the bar prevents the holder moving any further; the continued action of the tap then draws itself forward in the work, and moves the lug out of gear with the back pulley, and the tap ceases to revolve. To withdraw the tap, the work is pressed gently in the opposite direction, when the lug on the spindle comes in contact with the front pulley and the tap is run quickly out.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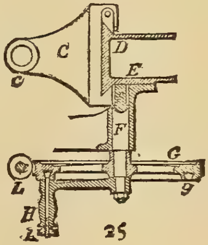
Drilling and Boring Machines.—Fig. 23 is a radial drilling machine by Gregson, Brown, and Son. The arm is capable of being worked round at any angle, the slide holding the spindle can also be worked at an angle by worm and wheel. The whole tool is very massive and strong for the work it has to perform. The spindle is 3 in. diameter, and long enough to drill a hole 20 in. deep, and there is sufficient range of velocity in the speed pulleys and gearing to obtain the right speed to drill from the smallest size up to a 15-in. cylinder. The driving apparatus is provided with two sets of pulleys for fast and slow speeds. The arm is 7 ft. long from the centre of the upright shaft, and the slide is moved backwards and forwards by a rack and pinion fixed on the top of the arm, and worked by a very simple contrivance. The tool can be converted into a slot drill if required. The upright standard is firmly fixed to a planed base-plate, which is 11 ft. long by 4 ft. wide,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and 6 in. deep. When the jib is worked to the top it will take in 5 ft. 6 in. from the top of the base-plate to the under side of the spindle nose, or 6 ft. to the under side of jib. The jib can be lowered 20 in. to within 3 ft. 10 in. of base-plate. It is worked up or down by a worm and wheel, and two sets of racks and steel pinions.

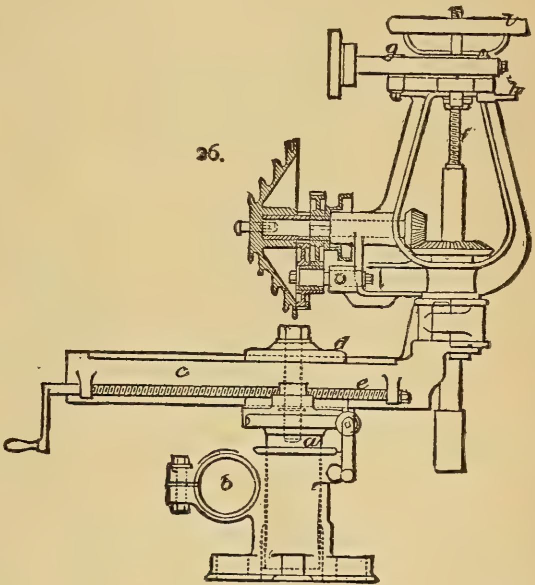
Fig. 24 is of an upright drilling machine by Ferris and Miles, of Philadelphia. The drill spindle A is counterbalanced by a weighted lever B attached directly to its upper extremity, this lever holding it up securely against a fast collar on its lower end, and thus preventing the breakage of drills by any lost motion. The spindle receives its rotary motion by bevel gear, having the ratio of 3 to 1, placed near the top of the machine, the spur with its face downwards to prevent dirt lodging in the teeth. The lower end of the spindle A is firmly supported in a bearing *c* of a long carriage or saddle C, which is gibbed to the guides D of the frame E, and traverses thereon a distance of 17 in. exactly in the manner of a lathe carriage upon its bed.

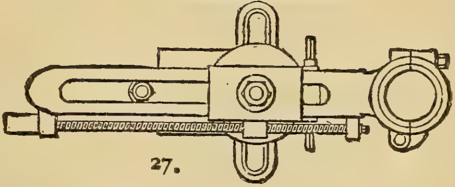
The carriage C, Fig. 25, has a rack *e* cut upon it, into which gears the pinion *f*, whose shaft F has a crank handle H fastened to it and a wormwheel G loose upon it, except when clamped by a pinch-bolt through the handle H. This pinch-bolt has a wedge-shaped head which plays in the annular slot *g* of the wormwheel G, and a pinch-nut *h* outside of the handle H. By tightening *h* the wedge-shaped head of the pinch-bolt is jammed in the annular slot *g*, and the handle H is clamped firmly to the wormwheel.

The automatic feed motion is taken off the spindle A by a belt working upon the cones *j* and J, the larger of which, J, is fast upon the rod K, and, by revolving, it serves to drive the worm screw L, when clamped thereto by the friction disc M and pinch-nut N in the conical handwheel Q. When thus clamped the screw L causes the wormwheel G to revolve. When the pinch-nut *h* is slack the carriage C, and with it the drill, may be thrown upward and downward rapidly or slowly at will by means of handle H, pinion *e*, and rack *f*. When the pinch-nut *h* is tightened the carriage may be traversed slowly, either by hand, by means of the conical handwheel Q, or automatically by tightening the pinch-nut N.

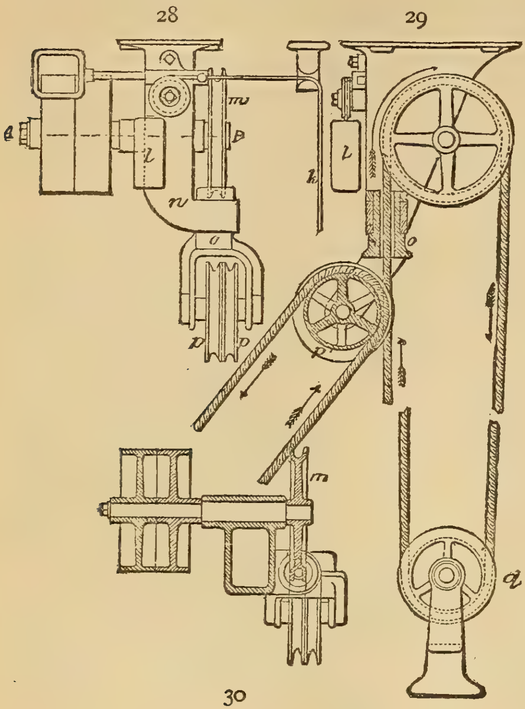
It is to be observed that in releasing the feed motion to run the drill up, the operator's hand, after releasing the pinch-nut *h*, is in exactly the right place at the handle H. Also in bringing down the drill to the point at which it is to have the feed put on, he has no additional movement of any kind to make. It will also be noticed that the handle H, by its pinion *f*, takes hold directly of the carriage with no idle gears to be driven as in the usual quick returns, and that the extremity of the spindle A guided by a traversing carriage C with long bearings, never protrudes from its bearings. The drill is always equally distant from its support, and must therefore drill a true hole.

The machine is provided with a table swinging upon its column in the usual manner, but also traversing upon its bracket by a screw. The slide is arranged with a socket in such a manner that the table can be removed and a convenient clamping vice secured in its place, also a pair of centres or an angle plate as may be required for various work.

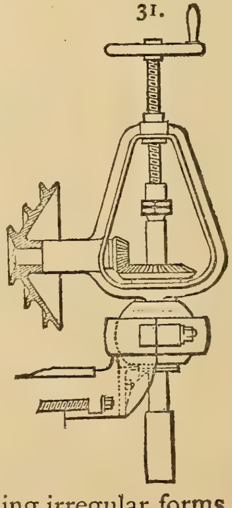




Portable drills are especially designed for use upon pieces of work of irregular form, or which from their size cannot be readily adjusted under a stationary drilling machine. Figs. 26, 27 show a side view and plan of the largest size machine by Thorne, De Haven, and Co., Philadelphia. It is mounted on a short cast-iron standard with a cruciform base, the latter being provided with slots through which bolts pass for securing the drill to the work. The post *a*, carrying the drill, is held either in the vertical bearing in the base, or for horizontal work it is placed in the horizontal bearing *b*. The radial arm *c* is held in position in the post by the bolt and plate *d*, the drill being traversed to and fro by means of the screw *e*, and rotated by a worm and tangent wheel. The end of the arm is furnished with a socket which carries the drill frame, and it can be turned round so as to bring always the cone pulley in a line with the driving belt.


28 29 30

The drill is driven by gearing, either direct from the cone, or through a system of back gearing shown in section, Fig. 26. The automatic feed is obtained from a small pulley on the main cone pulley-shaft, a strap passing from the former to a small pulley above, which drives a worm and rotates a nut, through which the screw spindle *f* passes. The worm is hinged at *g*, and can be thrown out of gear by turning a small eccentric at *h*, and the feed can then be worked by the handwheel *i*. In the smaller machines, as in Fig. 31, the back gear is omitted, and the drill is driven direct through the bevel pinion on the cone pulley-shaft. In one form also, the bearing in the end of the arm, instead of being cylindrical is made spherical, and the drill is mounted on a spherical boss, held in the bearing by a collar; when this latter is in position, the frame can only be rotated in a horizontal plane, and the spindle is kept square with the base, but if the collar is removed the frame can be set at any angle desired. This modification has many useful applications in drilling irregular forms.

31.


The mode of driving this drill is very ingenious, and is shown in the illustration, Figs. 28 to 30. The countershaft is driven by a strap passing through an eye, and which is shifted to the fast pulley when the cord *k* is pulled and held in position, the weight *l* always tending to throw the strap to the loose pulley. On the other end of the countershaft is a grooved pulley *m*, over which the cord passes which actuates the drill. Below this grooved pulley is a frame *n*, supporting a swing hanger *o*, the centre of which is hollow, as in Fig. 28. In this swing hanger are two idle pulleys *p*, so placed that the delivering edge of one of them is always in line with the receiving edge of the grooved pulley. The cord passes under the pulley *p*, over the grooved pulley, through the hole in the hanger *n*, and then hangs down, being kept tight by a weighted pulley *q*; it then passes around pulley *p′*, and over the cone on the drill. The weighted pulley is used so that as the drill is moved to varying distances from the countershaft, there may be an extra length of driving cord available. If more is required additional lengths can be added by hook-and eye connections.

32.

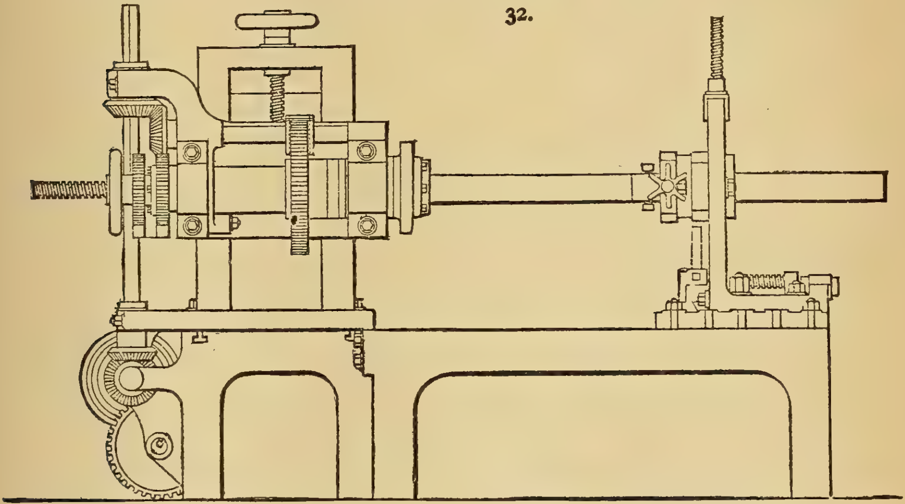
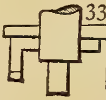


Fig. 32 is a special tool, designed by Hind and Son, Nottingham, to facilitate the boring and facing of engine cylinders and the like. The machine consists of a strong bed, upon which is fixed a vertical slide adjusted by screw and nut, and fastened by bolts and nuts in the tee-grooves. Upon this vertical slide is mounted a strong headstock carrying the boring sockets. This headstock is also adjusted by a screw vertically; the socket runs in parallel bearings, and is driven by a spur wheel 1¼ in. pitch, 4 in. broad on face, keyed on to the socket; the wheel is driven by a pinion, receiving its motion by mitre-wheels connecting the horizontal shaft with the vertical shaft, and the vertical shaft is driven by mitre-wheels on the lower horizontal shaft having bearings in the bed of the machine. The shaft has double power gear, and a 4-speed cone, thus allowing the headstock to be adjusted in the vertical and transverse movements. The boring bar is fed self-acting, by a screw deriving its motion from a series of wheels driven from the end of the boring socket, and is furnished with a wheel for adjustment by hand.

The bed to receive the work is fixed at right angles to the transverse movement of the headstock, it has a planed surface and slot holes to bolt work down. There is a boring bar-stay and apparatus for facing the ends of the cylinders, at the same time the boring operation is proceeding. This consists of a base-plate adjustable and fastened to the bed, upon which is a vertical slide or bracket, adjusted to the bottom plate by a screw and bolted to tee-grooves; upon this bracket is a crosshead and bearing to stay the boring bar. The crosshead is furnished with two tool-holders, capable of being worked to or from the centre of bar or crossheads by a self-acting tappet motion acting on a star-wheel working the screw in the crosshead. The facing apparatus can be disconnected from the boring bar when not wanted, and can be adjusted vertically to suit height of boring bar. This machine will bore holes up to 16 in. diameter, traverse the boring bar a distance of 2 ft. 6 in., and admit articles on the table up to 28 in. centres. The machine can be made to admit greater lengths and heights, and can be furnished with one or more boring heads, either on one side of the work table or at right angles for boring holes at right angles to each other, over any specified area. The machine can also be used as a turning and facing lathe for various articles, by fitting a suitable chuck on the boring socket, and fixing a compound slide rest on the bed of the machine.

The operation of drilling or boring tube holes through boiler plates and other similar work is a somewhat complex and costly process by the ordinary methods in use. We will assume, as an example, that a 3-in. hole is to be drilled accurately to a circle marked out on a tube plate ¾-in thick. It is usual to drill, say a ¾-in. or ⅞-in. hole in the centre with an ordinary drill. This hole, which is to act as the guide for the accuracy of the subsequent work, must of necessity be carefully drilled in the exact centre, to a circle first set out on the plate, and it is well known that drills are very apt to run this way or that way, according either to the form in which they are ground, or according to the perfection or imperfection of the centre punch mark from which they start, or from the defective condition of the drilling machine itself, any of which causes, or all combined, will produce irregular work. This central-hole drill labours under the disadvantage of all ordinary drills as compared with cutters, inasmuch as considerable pressure is required to force the centre or V edge of the drill into the iron, to the extent of the thickness of the shaving or drilling taken off by the cutting edge at each revolution of the drill; and the blunter the drill the greater is the pressure required to enable the drill to cut at all. Added to this, the hole through a $\frac{3}{4}$-in. plate is not complete till the drill has been fed down through a depth of 1 in. or $1\frac{1}{8}$ in. or more, according to the length of the V point of the drill. After this hole has been made a second work has to be done, and generally this is performed by a cutter specially made for the purpose, either of one of the shapes, Figs. 33 to 35, or of some such form. In these cutters the centre portion is supposed to fit the hole first drilled, and be the guide to ensure a true hole of the larger diameter. As often as not, however, the central pin does not fit the hole well, a defect which, whatever may be its origin, ends in the result being either a bad hole, or one out of its proper position, or even a combination of the two.



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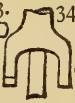

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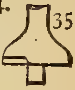

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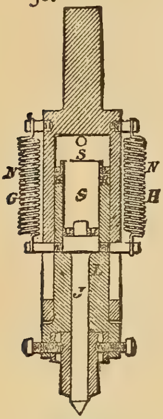
McKay's drill is designed to overcome these defects, and this with a minimum of setting out, a less amount of machine power, and in the shortest time possible with a given thickness of plate and diameter of hole.

Referring to Figs. 36 to 39 it will be seen that it consists of a main body, of which the upper end is turned to fit the socket of a drilling machine, while the lower part forms a cylinder or case containing a small ram. Into the ram L, there are two short studs screwed through two slots formed in the outer case, by means of which a pair of spiral springs keep the ram fully home till caused to move, and draw it home again when the movement is over. This ram is also bored out from its upper end and contains an inner plunger of steel, having a shoulder J at its upper, and a pointed centre at the lower, end. L and J are each fitted with an hydraulic leather within the case. A small hole at the top of the chamber S, permits the tool to be charged with water or oil, and when the hole is closed by a screw-plug, the apparatus will be ready for work, with the exception of putting in the required cutters M according to the size hole to be cut. The centre point being placed upon a centre-punch mark made on a plate to be drilled, and the pressure of the feed of the machine brought down upon the case, J will move upwards within the cylinder S, and the oil having no way of escape presses hydrostatically within the chamber and forces the larger plunger downwards. The cutters M are thus brought down to the surface of the plate, while the centre remains also in the centre mark. If the machine is now started, the feed pressure will cause the cutters to perform their cutting work, while the centre pin still remains upon the first centre. So soon as the cutters have passed through the plate, and if there is no resistance underneath, the central pin will at once push the core down by the hydrostatic pressure due to the resistance afforded by the two external springs, which will draw the larger ram home directly the hole is made.

36.



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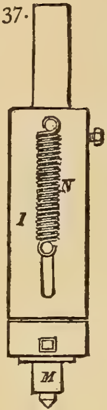

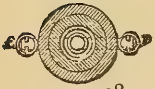

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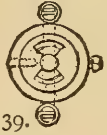


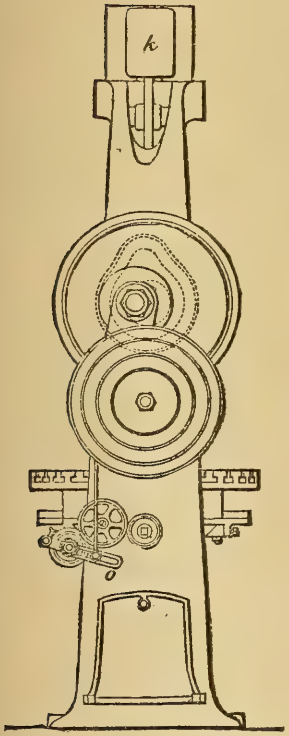
39.

In this tool the cutters are differently formed and are also more easily constructed, and the equal pressure exerted by the fluid on each ram ensures a fair division of labour, seldom rightly obtained by such forms of cutters as at first described. The results of the use of this boring tool are, first, perfect accuracy of position when once a clean and deep centre-punch mark has been made; secondly, a true hole with a minimum quantity of metal cut away by cutters; thirdly, the work performed is done in the least time compatible with the circumstances of the case.

The tools for tube-hole boring, supplied with each holder, are made so as to cut holes varying ⅛ in. in diameter to suit the two ends of boiler tubes. Thus a 3-in. size is arranged to cut both 3-in. and 3⅛-inch holes, and so on.

Slotting Machine.—The slotting machine of W. Sellers and Co., Philadelphia, Figs. 40 to 43, has sufficient over-reach to enable it to slot the eye of a wheel 48 in. in diameter. The slotting tool is operated by means of a crank driven by what is known as the Whitworth motion, giving a slow movement under cut and a quick return. The crank is adjustable in length of stroke, the maximum being 12 in. This adjustment is effected by a screw *p* in the crank plate, the adjustment of the connection of the connecting rod with the slotting bar is also by means of a screw *p′*, so as to regulate the position of the slotting bar in height from the table upon which the work rests.

40.



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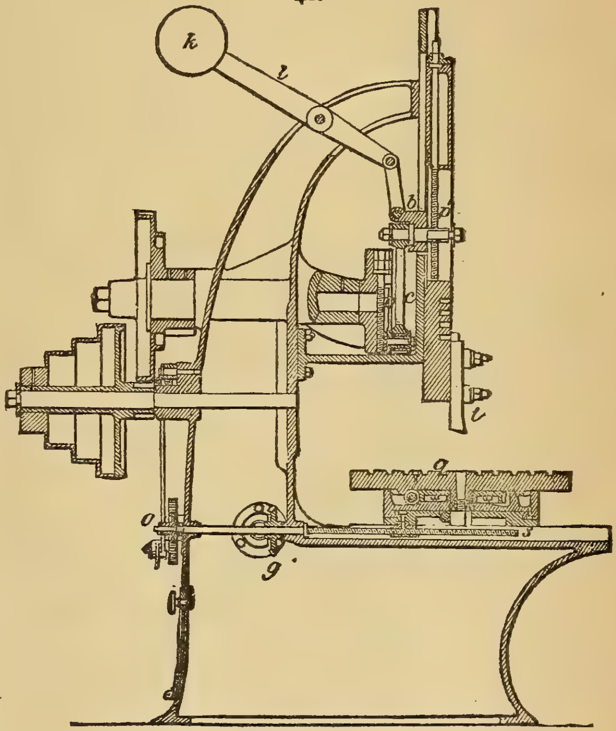
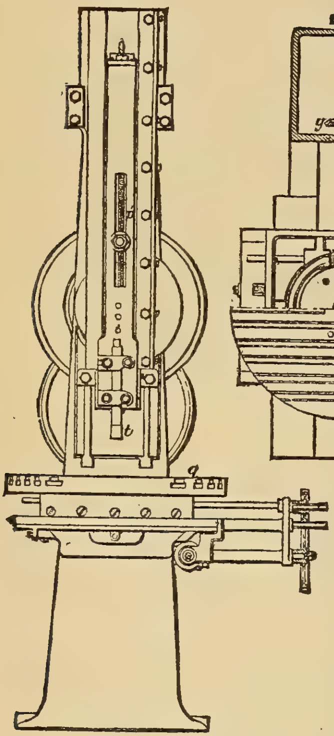


The attachment of the connecting rod *c* to the slotting bar is by means of a wrought-iron block *b*, always in connection with a counterbalance lever *l*. The counterbalance *k* is in excess of the weight of the slotting bar and any ordinary cutting tool, so as to take up all lost motion, and steady the operation of the machine under cut.

The bearing or slide carrying the slotting bar is adjustable to suit the different heights of work, and enables the bar to be guided as near the work as possible. When the nature of the work will permit, the supporting bearing can be carried quite close to the table, thus giving a firm backing to the tool during its whole stroke, and ensuring steadiness of motion. It is noticeable that the connection of the connecting rod to the slotting bar is off to one side of the centre of the crank, on the pulling down or working side of the crank. This places the crank and connecting rod in the best relation for work, with the least side strain on the vertical slide under cut, while on the upstroke its consequent increased obliquity to the line of motion does no harm. The compound table *q* upon which the work is bolted consists of the usual compound slide rests of broad surface, with a rotating table on top of the upper cross slide, all provided with automatic feeds. These feeds are obtained from one primary motion *o*, a ratchet feed wheel operated by a cam at the back of the large driving wheel. This cam is so constructed as to ensure the occurrence of the feed at the top of the stroke, while the crank is passing its dead centre.

42.



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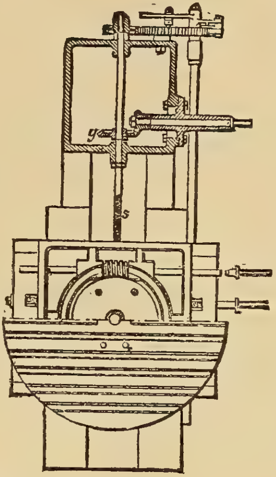
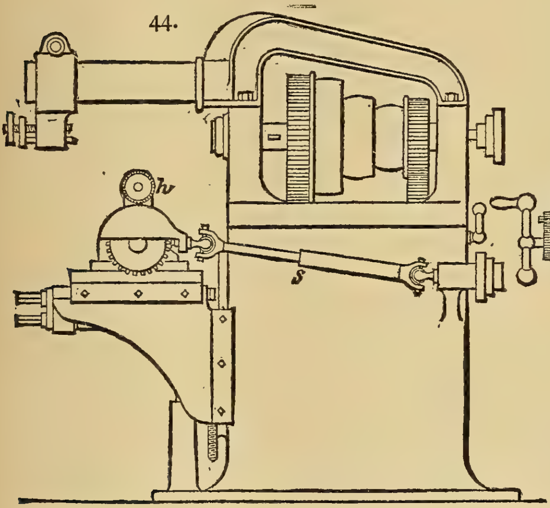


The conveyance of this feed to any required part of the machine is effected by means of one gear wheel *g*, Figs. 41, 43, with a square hole in the eye, to fit on the square ends of the various feed screws and shafts. Thus for the longitudinal feed this wheel, placed on the end of the feed screw *s* at the back of the bed, Fig. 43, gears into a wheel between the ratchet wheel and this screw, while the cross feed and circular feed are driven from a wheel travelling with the compound table, and driven from the ratchet wheel by bevels, and having its pitch line the same distance from both of the two shafts, so as to be within reach of either with the same wheel. The longitudinal feed by hand is obtained by bevel wheels within the bed, and a squared end for a crank within reach of the workman when he is handling the other feeds. There is scarcely any machine tool requiring more close watching on the part of the workman on the class of work it is required to do; it seldom takes long cuts, it generally being but a little while under power feed at a time, and the amount of production, all other things being equal, depends upon the readiness with which the attendant workman can do his part of the movement, in adjusting and readjusting the work in various positions, and keeping the tool under cut as much of the time as possible. This can be illustrated in one class of work in common practice, namely, the key seats of wheels. Care is required to adjust the wheel in place, so as to have the sides of the key seat parallel with a diameter line. This requires some little time, while but few strokes of the slotting tool are required to cut the key seat after it is made ready; it is evident that convenience of adjustment in such work will materially influence the amount done.

44.



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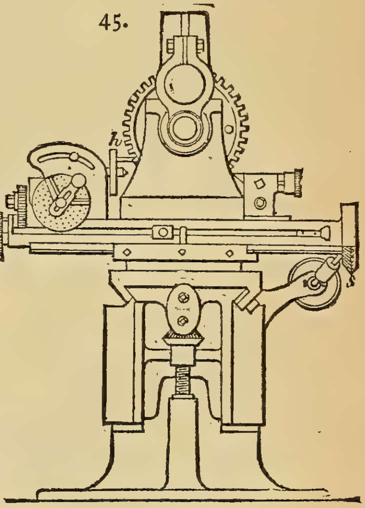
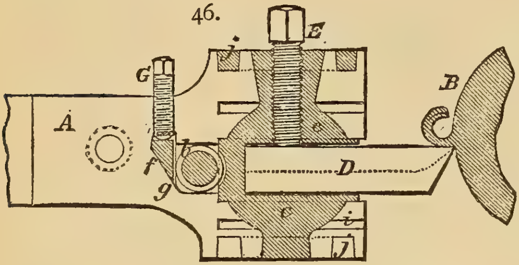
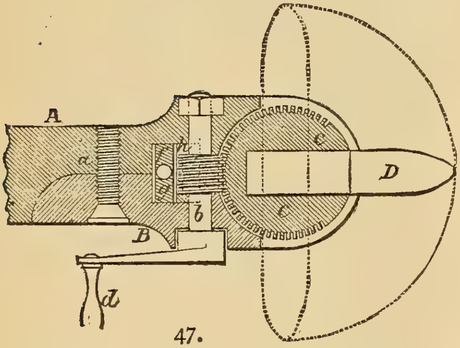


Milling Machine.—Figs. 44, 45 show a milling machine made by the Brown and Sharpe Manufacturing Company, Lowell, Mass.; the feed motion is communicated to the carriage through a small telescopic shaft *s*, fitted with Hook's joints, so that the slide in which the carriage moves may be set at an angle with the centre line of the spindle. The small headstock *h*, carrying the centre at the end of the carriage has also an angular motion in the vertical plane, so arranged that whatever the angle may be the centre remains in gear with the feed motion. These additional movements render the machine capable of a wide range of application, for besides ordinary milling a great variety of other work, such as reamers, twist drills, milling cutters, and rosebits, may be produced, and the teeth of spur and bevel wheels may be also cut. The cutters used in these machines are of peculiar shape, and are of the same cross section throughout, so that by grinding them on the face they may be sharpened without altering their form. Machines having rotary cutters with detached teeth are sometimes used for operating upon a larger class of work, where it is necessary to take heavy cuts.

46.





47.

Tool Holders.—Machine tool-cutters formed of comparatively small pieces of steel held in special tool-holders in place of the ordinary tools, forged from steel bars of various dimensions, are largely employed.

Figs. 46 to 55 are of Baville's system of tool-holders, as made by Greenwood and Batley of Leeds; Figs. 46, 47 are adapted for lathe tools. The tool is shown in longitudinal section; Fig. 46; horizontal section, Fig. 47; it consists of two main parts A and B fitted together and fastened by screws *a*, so as to present a cylindrical head, in the interior of which is placed the movable nut-shaped piece C, which holds the cutter D; this nut fitted exactly to the receptacle formed to hold it, in the interior of the parts A and B, is of a spherical shape in the middle, with a conical part above and below, terminating in a cylindrical tenon forming two pivots, on which it can make a rotary movement of half a circle. The circumference of this sphere is cut with a thread gearing into a worm *b*, the journals of which are made square at the ends to receive a handle *d*, by the aid of which it can be turned. In order to hold the tool firmly, C is pierced by an angular opening, Fig. 46, corresponding to the section D of the cutter, which fits in very accurately, leaving room, however, for the insertion of a wedge-shaped piece, which is screwed down tightly by the screw E.

A tool like this can act at will perpendicularly or parallel to the axis of the lathe, or in any of the intermediate oblique positions; further by means of its simple form and mobility, it can be employed in working on certain interiors, ordinarily requiring a tool forged to a special shape.

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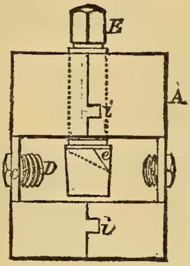

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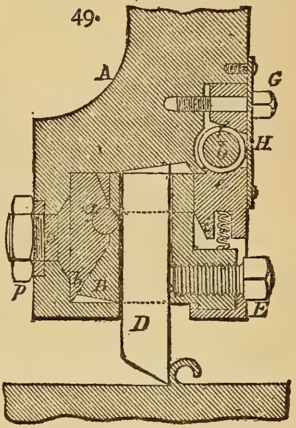

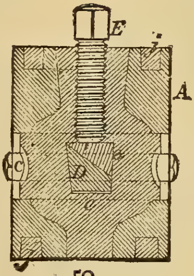

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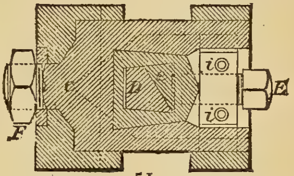

51.

A brake is therefore applied to the axis of the worm *b*, in such a manner as to ensure the rigidity of the nut C in any desired position; this brake consists of a wedge *f*, acted upon by means of the screw G, so as to press it by the interposition of the plate *g*, Fig. 47, on the two half journals *h*, embracing the axis of the screw half its circumference. The two jaws A and B are joined very accurately one upon the other, by means of two tenons which go into the grooves *i*, Fig. 46, and in addition to the screw *a*, the two parts of the head of the tool-holders are fixed together above and below the nut, by means of two rings *j*, fitted in like grooves.

In the tool-holder for planing machines, Figs. 48 to 51, the same general features in principle are observable as in the preceding one, but it has in addition a small special mechanism, so arranged as to permit the tool being slightly inclined on the return stroke, in order to prevent it from becoming blunt, by rubbing on the work in going backwards previous to commencing a new cut. The majority of planing machines are so constructed as to do this, but the whole tool-box has to be inclined, whereas in this case it is only the cutter which needs moving, and being very light the cutting edge does not get blunted by the friction so soon as in the machines now in use, there being less weight of tool-box on the edge of the tool.

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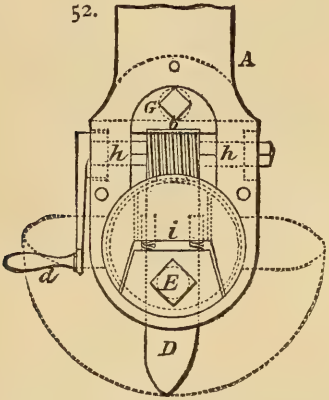

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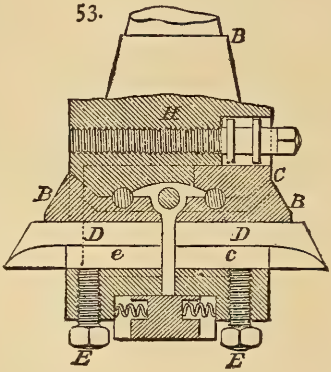

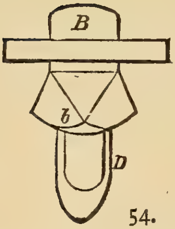

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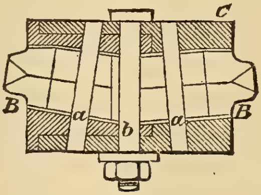
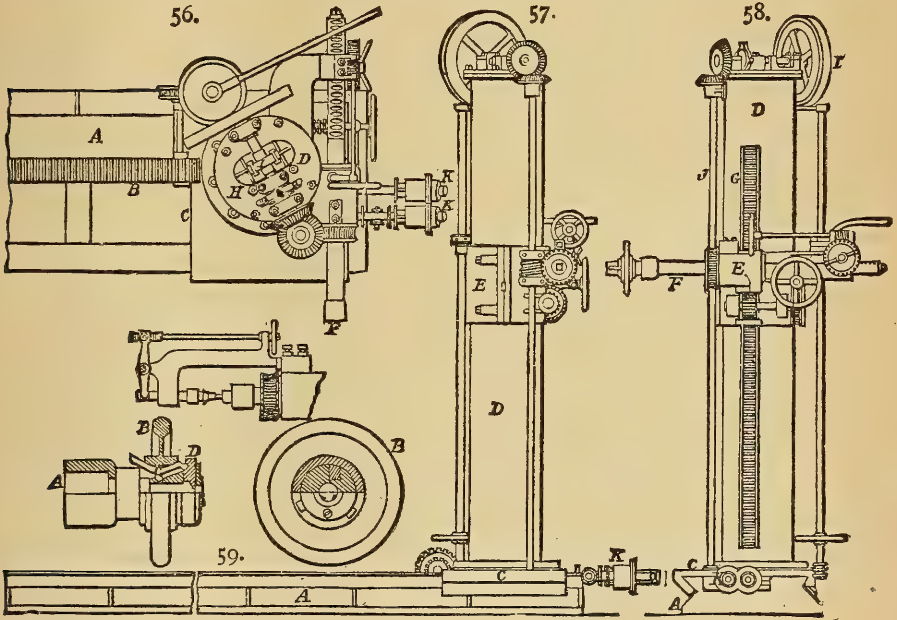


55.

This planing tool-holder is shown in vertical section, Fig. 49. Fig. 51 is a sectional plan, and Fig. 48 a back view of the box to receive the tool. It is composed of a vertical piece A, terminating in a cylindrical part in which the head C is adjustable; this as in the preceding case can rotate by the action of the worm *b*, and is widened out to receive the tool-box B, in which the tool D is held by the screw E. The tool-box B does not fit close into the space left to hold it in the head C; this permits a slight oscillating movement on the steel pin *a*, fitted half into each of the two pieces, Fig. 49.

When cutting, the tool-box B occupies the position, Fig. 49, and takes its bearings on the head at the angular parts, *b′*, Fig. 49, so as to maintain the rigidity of the cutter by its adjustment. In the movement in the contrary direction, the simple contact of the cutter on the piece under operation is sufficient to make the tool-box B, rotating on the pin *a*, reverse itself and give the necessary inclination, and further to provide against the tool box B being shaken in its various motions, the two springs bring it back constantly to the proper working position. The upper part of the head C is toothed to gear into the worm *b*, by means of which it can rotate in its own bearings and give the desired position to the cutter; it terminates with a screwed end on which the tightening nut F is fitted so as to hold it firmly in the tool-holder. The worm is also provided with a brake composed of the screw G and wedge *f*, which act on the journals *h*, clasping the screw spindle. The different parts are covered by a plate H, Fig. 49, screwed on the tool-holder.


56. 57. 58. 59.

Figs. 52 to 55 are of a double tool-holder with horizontal cutters for a slotting machine. This latter tool-holder, by its conical piece

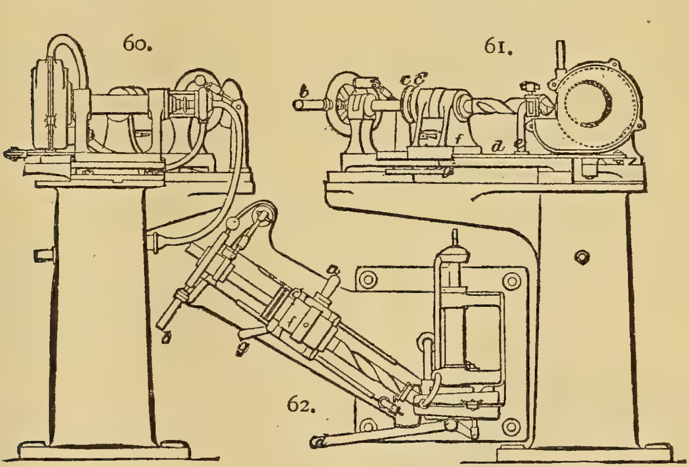
B may be fitted on the head of any kind of slotting machine, but is specially arranged for slotting axle boxes. For this purpose it is made double, that is to say, provided with two cutters D and D′, placed horizontally, and in such a manner as to work simultaneously; each one is fixed in an oscillating box, one of the boxes being fixed in the slide rest C′, moved by the screw H, by means of which the extreme distance between the two cutters can be adjusted at will; Fig. 55 shows a sectional plan through the pins *a*, and shows the centre bolt *b*, which is used to assure the firmness of the block C′, with the conical head B. These two pieces carrying the movable parts, constitute the whole of the tool-holder.

Machine for Fixing Boiler Stays.—In the manufacture of steam boilers when the shell has been drilled it is taken apart, and all the drill-burrs removed from the plates. The outside and inside edges of the holes are countersunk by machine. The plates are put together again and riveted up. The next step is to lower the furnaces and combustion chambers into the shells, to which the front plates are riveted. The screw stay holes are then drilled and tapped, and the stays are screwed. Fig. 57 is an elevation; Fig. 56, a plan; Fig. 58, an end view; and Fig. 59, details of a machine invented by Allan, of Sunderland, for this purpose. It consists of a hollow pillar D, inside of which is placed a small steam engine, with a flywheel I; up and down the pillar slides a saddle E. This is reversed and lowered by a rack and beam. The pillar is moved on the bed A of the machine on the inverted V foot C. Steam is introduced through flexible pipes and stuffing boxes J, and the various movements of the machine are controlled by one man working the hand-wheels. The bar F, Fig. 58, carries the holder, shown to a large scale in Fig. 59, which is arranged to rotate, and can at the same time be drawn backwards and forwards at will by the rack.

The boiler is laid down and levelled, with the back end close to the bed-plate. The pillar can then traverse back and forward across the end of the boiler. A drill is then put into the end F, and the machine being started, the holes are drilled one after another in the two plates true and at right angles to the boiler plates. The drill is moved over the boiler end by the gearing F, which is made either to raise or lower the saddle E, or to move the whole pillar back or forward. When the holes have been drilled, a tap is substituted for the drill, and they are screwed. Next the stays are substituted for the tap, and put in place, and finally a cutter-head is placed on, and the stay ends all cut off accurately to length and shape.

Emery Grinders.—The cleanliness of emery wheels, and their quick cutting character, compared with natural grindstones, render them convenient for sharpening tools. They are used to a considerable extent for sharpening saws, mill picks, paper-cutting knives, lathe tools, drills, and shear blades, and are found to impart a better edge to the tool than a grindstone. In Van Haagen's twist drill grinders, the drill is placed in a chuck that presents it at the proper angle to the edge of the wheel, and by an ingenious link connection, the same movement of the handle for turning the drill round, also gives the proper motion for backing it off behind the cutting lip. A small centrifugal pump keeps the wheel supplied with water, which is prevented from flying off by a hood that covers the wheel, except at the cutting point.

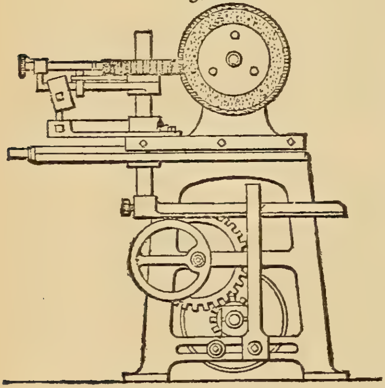
Figs. 60 to 62 are of this twist drill grinding machine, constructed by Thomson, Sterne, and Co., of Glasgow. It consists of a hollow standard having at its top a slide for the headstock carrying the emery wheel spindle. This headstock can be moved to and fro on its slide by the lever *d*. The spindle carries at one end the emery wheel, while at the other it drives a small centrifugal pump, which draws water from the hollow standard serving as a water tank, and discharges it on the edge of the emery wheel, the connections between the pump and the tank and emery wheel casing, respectively, being made by indiarubber tubing. The wheel is so mounted that



it can be shifted back as the emery wheel wears, and the water can thus always be discharged effectively on the wheel. The wheel spindle is driven at a speed of about 2400 revolutions a minute.

At an angle of 45° with the wheel spindle, there branches off from the standard an arm carrying the sliding head, in which the drill to be ground is mounted. In the grinding of a drill the handles *a* and *b* are loosened. From the bearing post *e*, the finger which is used in the preliminary adjustment of the wheel is removed, and the proper size of guide ring for the drill to be ground fixed on; the drill is placed in the hollow spindle or socket made to fit the drill and spindle, its end resting in the guide ring, with the left hand of the operator on the milled flanges *c c′*; the spindle is adjusted to allow about ⅝-in. play between the flange *c′* and the head *f*; the head *f* and the spindle are moved, so that the end of the drill is brought to the face of the wheel, and the lever *g* tightened with the right hand. The machine is then started, and the amount of water supply regulated by raising or lowering the flexible tube through the eye on the headstock; the drill is adjusted forward with the left hand on the flanges *c c′*, one cutting edge of the drill being brought horizontal against the face of the wheel, and the drill pressed forward until the desired amount is cut away; the handles *a* and *b* are tightened firmly; then the lever *d* worked to move the emery wheel back and forward across the face of the drill, and at the same time the handle *b* brought down very slowly; after which the drill is rotated quickly against the face of the wheel by moving the handle *b* up and down, until a smooth finish is given to the end of the drill; the handle *b* is loosened, and the spring stud pulled down underneath the head *f*. The handle *a* is thrown over, and the handle *b* tightened, the operation being repeated as in grinding the first side of the drill. After setting the handle *a* it must not be loosened until both cutting edges of the drill are finished. To prevent the water from freezing in the tank, thereby endangering the pedestal, it is recommended to add

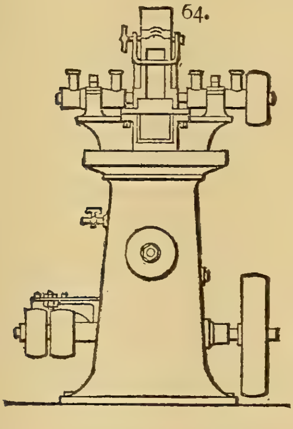
63.



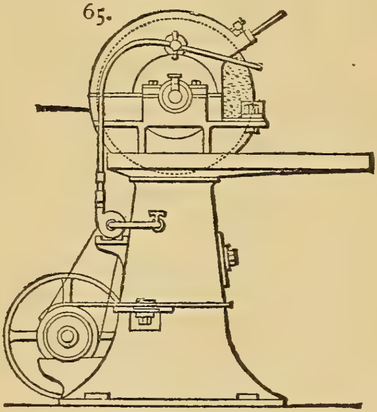
a small quantity of glycerine, otherwise the water should not be allowed to remain in the tank over-night during frosty weather.

An application of emery wheels with moulded edges is shown, Fig. 63, which is a machine made by Slack's Emery Wheel Co. for cleaning out the teeth of wheels. The emery wheel is turned to the shape of the space between the teeth, and revolves in a small headstock, while the wheel, or pinion, being operated on is moved vertically in front of it by means of an eccentric motion, and at the end of each stroke is turned automatically through the space of one tooth. These machines are exclusively used by makers of textile machinery, and will clean from 1500 to 2000 teeth an hour.

A similar arrangement is used in the Universal Tool Grinders of Thomson, Sterne, and Co. One of these machines is shown in Figs. 64, 65. It will be seen that the centrifugal pump is placed at the back of the machine, and is driven from a pulley on the countershaft. The safety grinding ring used with these machines is made so that the sides of the emery ring are gripped between two washers with dovetail grooves in them, which would keep the pieces in position should the ring break. Corundum, which is a pure form of emery, and a harder and sharper abrasive than the emery of commerce, is used where it is important that the wheel should remain of the same diameter and shape. Morton Poole's system of grinding chilled calender rolls is an instance of the application of corundum wheels; there are several peculiar features about this process of grinding, and an extremely accurate result is obtained.

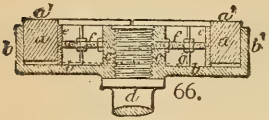


64.



65.

It is well known to all who have had experience in emery grinding that to perform rapid cutting a very high speed of the wheels is desirable. But it so happens that those emery compounds which are best adapted for quick cutting have also the least cohesive strength, and hence the speed at which it is possible to drive safely ordinary discs made of such compounds is limited.



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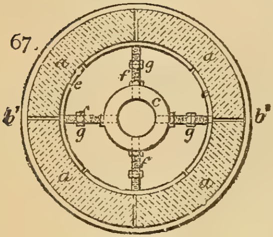

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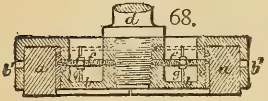


68.

To obviate this is the object of the device invented by Butler, Figs. 66, 67, where, instead of a disc of emery, a ring is employed made up of segments *a a*. These segments are placed within the flange *b'* of a casting *b*, and inside them are arranged the curved plates *e e*, which are tightened up against the grinding segments by the screws *f f*, interposed between the plates *e* and the boss *c*. The pairs of locked nuts *g g* are used for balancing the wheel, and they enable this balancing, an important matter in wheels driven at a high speed, to be accomplished very readily and accurately. Fig. 68 relates to an arrangement differing slightly from that of Fig. 66, the casting being, in this case, of such form that the plain disc *b* is interposed between the adjusting screws *f* and the work which is being ground. It will be understood that the grinding is performed by bringing the work against the annular surfaces *a'*, presented by the grinding blocks instead of against the periphery of a wheel as is usual. As the surface *a'* wears away, the grinding segments are shifted further out, a portion of the thickness of the segments being made of a non-grinding compound, so that they may be held firmly until all the grinding part is utilized.

Segments held in the way described can be driven with perfect safety at exceedingly high speeds, while the manner in which they are held is such, that there is nothing about the device likely to catch against work or do damage by anything falling on it. This is an important matter concerning the safety of the workmen using the wheels.

Ransome's emery wheels are much esteemed in English works, and from the circular of the makers, A. and H. Bateman and Co., of Greenwich, we give the following practical remarks, which apply generally to emery wheels, on their use :—

"It is well to run a coarse and a fine wheel at opposite ends of the same spindle, doing the rough work on the former and finishing up on the latter. Far more work can be got out of the wheels by applying the work lightly to them, than by pressing or crowding it; the latter only heats the metal, makes the wheel glaze, and often go out of truth.

"Speed has a great deal to do with result; from considerable experience, a surface speed of 4000 to 4500 ft. a minute, say 1350 revolutions of the spindle for a 12-in. wheel, is recommended, although a thick wheel may be run one-third faster with advantage, and good work may be got out of a slower speed.

"A foundation for the machine, good enough for slow speeds, will not do for high ones. Any vibration or tremor while at work is certain to produce bad results. It is not enough to screw a spindle firmly to a bench or table, the latter must itself be firm and rigid. In self-contained machines, a good concrete foundation is necessary; the expense will not be grudged, when the results are compared with those obtained from a machine on a shaky foundation. It must be remembered, that a large amount of centrifugal force is developed in a disc revolving many hundred times in a minute, and this must be met by firm foundations, and proper screwing up of the washers and side plates. Too much care cannot be taken on these points."

To A. and H. Bateman and Co. are also due the subjoined practical suggestions :—

"Examine emery wheels and machinery at least once a day.

"Remedy any defects at once, and on no account go on working with anything out of order. If a machine vibrates, add or alter requisite fittings. If a wheel is chipped or out of truth, true it with a black diamond. This may be done while running at full speed, care being taken to touch the wheel very lightly. After trueing, the wheel will be dull; rough it by running it against a piece of copper, or a piece of hard coke. Do this frequently; it makes work better, and wastes the wheel far less than waiting until it is very much 'out.'

"Never let the spindle jump or get hot, either will injure the wheel and produce bad work.

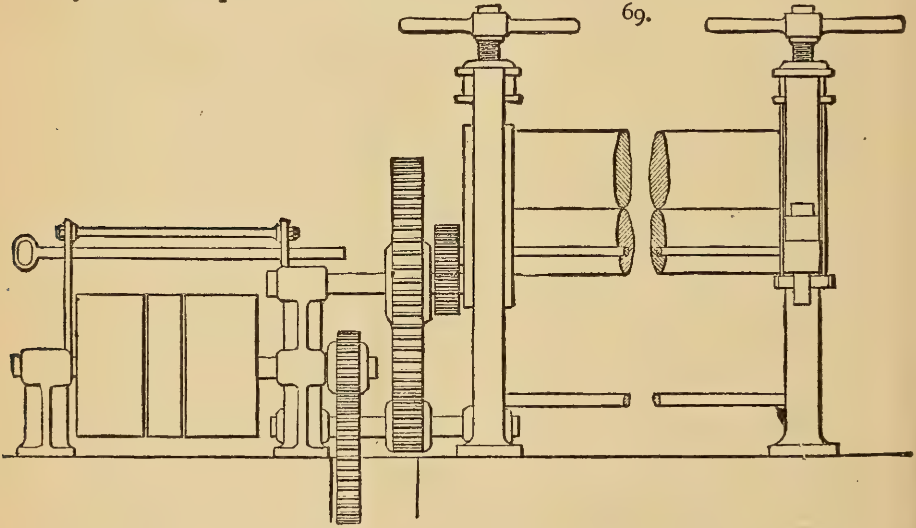
"See that side plates fit the spindle, and are fairly true. Screw up firmly, but not so tight as to crush the wheel. Do not use too long a spanner, it is difficult to estimate the force applied by means of a screw and long lever.

"Be careful to run the wheels at about the indicated speed; they wear out quicker if run much slower, and are apt to go out of truth, and an unnecessary risk is run if the speed be too great. Ascertain the speed by means of a counter. Calculation by size of pulleys is not very reliable, owing to the difficulty of making proper allowance for slip.

"If working with water, let it be applied close to the work, through a small orifice in a pipe under some pressure, either from the main, or from an elevated cistern. The wind caused by the wheel will otherwise tend to blow the water away. If too much is used it will fly off and cause inconvenience. Generally, working dry will be found preferable, but for tools and small work water is necessary.

"With tools and small work, hold in the right hand and press near the end with some of the fingers of the left hand. The moment the heat becomes uncomfortable, dip the work in water standing by, and then replace it on the wheel dripping, it not being necessary to dry it. Heat that will not hurt the fingers, will not injure the temper of the steel.

69.



"If a wheel breaks, nearly if not all the fragments will fly in the line of rotation. In grinding, therefore, stand as clear as possible of this line, to avoid injury in case of accident. Railway trains sometimes come to grief. An emery wheel running the same speed may do the same, but will not with proper care.

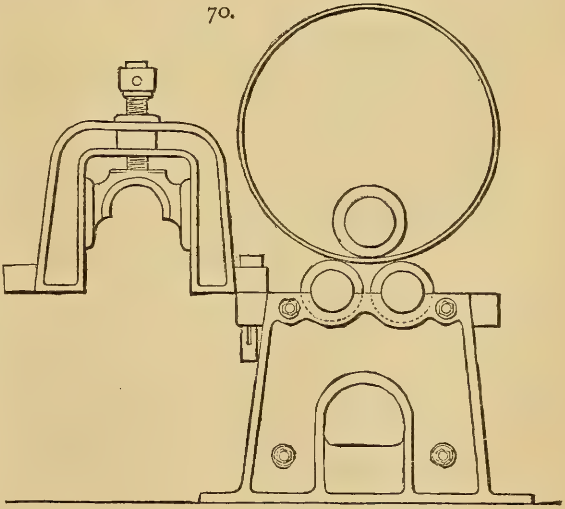
"Mount the wheels with the proper washers, and do not strip them off and put on others.

"Most important of all, remember that fair working gives best work. Forcing work against a wheel injures both, causes risk of accident, hastens the wear of the wheel, frequently causes glazing, which never happens with proper grinding, and is sure to wear a wheel untrue and involve very frequent trueing up."

There is but one limit to the use of emery wheels for fettling castings, and that is the size and weight of the castings. All castings, whether iron or brass, not too heavy or unshapely to be readily handled, should be fettled by the solid emery wheels, and it is placed beyond dispute by the experience of years, that this plan is cheaper and more practical than any other.

We see little reason to doubt that the solid wheel will in time entirely displace the grindstone. There is really no advantage in the very large size of grindstones, and the great variation between their maximum and minimum size, causes much inconvenience to the workman. The size of emery wheels is such that they occupy but little space, and are mounted with the greatest ease and speed. They are so strong that they can be run at an immense speed, and being composed of angular grains of a mineral only inferior in hardness to a diamond, they cut much more rapidly than grindstones, whose uneven texture is mainly caused by round and waterworn particles of silica. While the stones have to be roughed and picked from time to time, no really good emery wheel ever requires such treatment, presenting always a fresh, free, sharp-cutting surface. In consequence of the hardness of the surface and the very high speed, the work needs to be lightly touched to the wheel, and the selection of heavy men as

70.

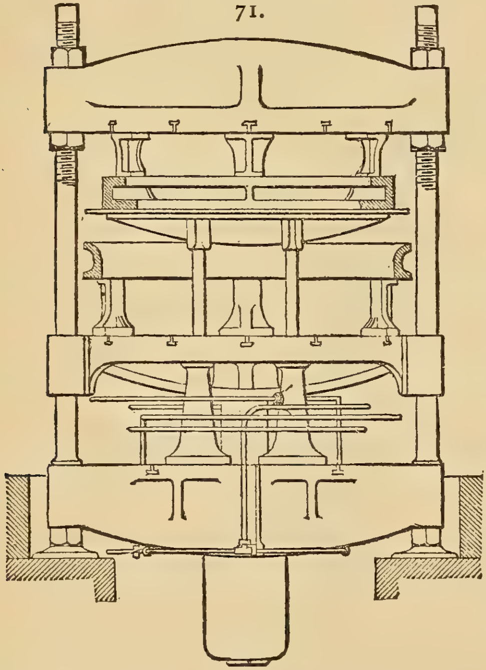


grinders is done away with, as are also the swinging boards, housings, and appliances for getting pressure. Owing to the moderate size of the wheels, they can be easily turned with diamond tools, and thus always revolve as perfect circles, instead of becoming eccentric as the stones do.

Rolling Machines.—Figs. 69, 70 illustrate a set of plate-bending rolls made by Grant and Macfarlane, of Johnstone, near Glasgow. It will be seen that the upper part of the frame carrying the bearing and elevating screw is made in the form of an arch, and is attached to the lower part by two bolts; when necessary, one of these bolts may be removed, and the top frame swung clear round on the other. Bent plates may be straightened in machines of this kind by running them through the rolls, with the top roll set to neutralize the existing curves.

Angle-iron, T-iron, and bulb-iron may be bent in the same way as plates if grooves of the proper shape are turned in the rolls; but in the machines usually employed for this purpose the works are placed vertically, and project clear of the frame. In the machines for bending garboard strakes, the garboard strake is the line of plates next the keel of a ship, the plate to be bent is clamped to a table, and the bending-roll brought to bear upon it by a powerfully-geared quadrant at each end. Machines for flanging and preparing the edges of plates are now generally used in the best boiler works, and not only effect a considerable saving of time, but turn out cleaner work than that done by hand.

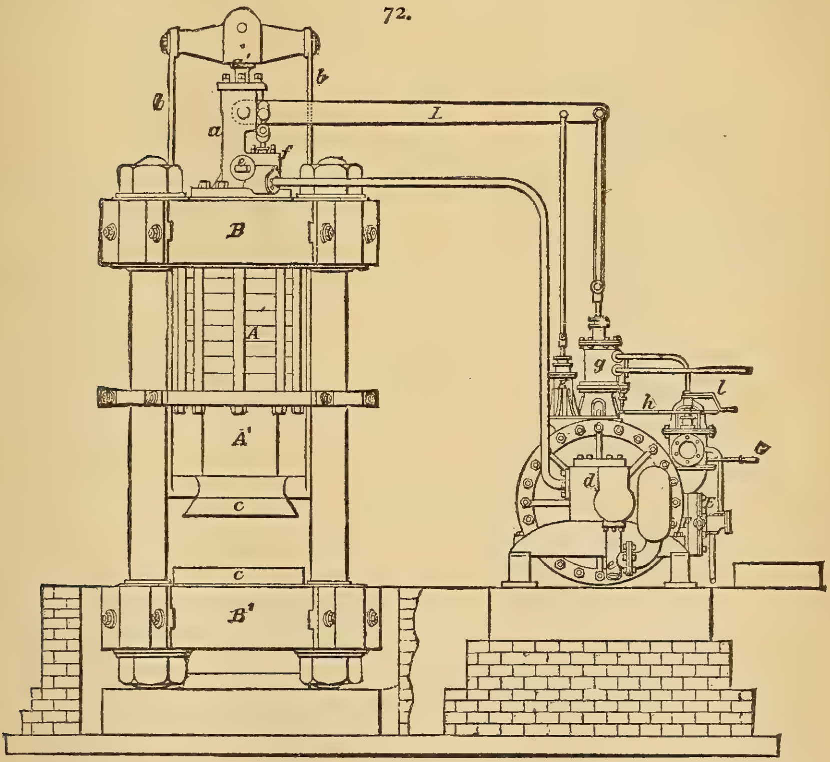
71.



Hydraulic Tools.—For circular work, the most rapid way of forming a flange is to give a rotary motion to the work, and deflect the edge by bringing rollers to bear upon it. Where the work is irregular, and cannot be operated upon by a rotary machine of this kind, the flanging is usually performed by pressing the work between dies, on the plan of Piedbœuf's hydraulic flanging machine, Fig. 71, a similar arrangement of hollow dies is employed, except that the movable die is fixed on the plunger of a hydraulic press.

The plate required to be flanged, having been properly heated, is drawn out from the furnace over iron bars, on to the annular ring, Fig. 71. The four small plungers carrying the table are then opened to the accumulator pressure. This table, rising up quickly, firmly holds the hot-plate against the top die, until the pressure being admitted into the large cylinder, the ram of this also rises, carrying

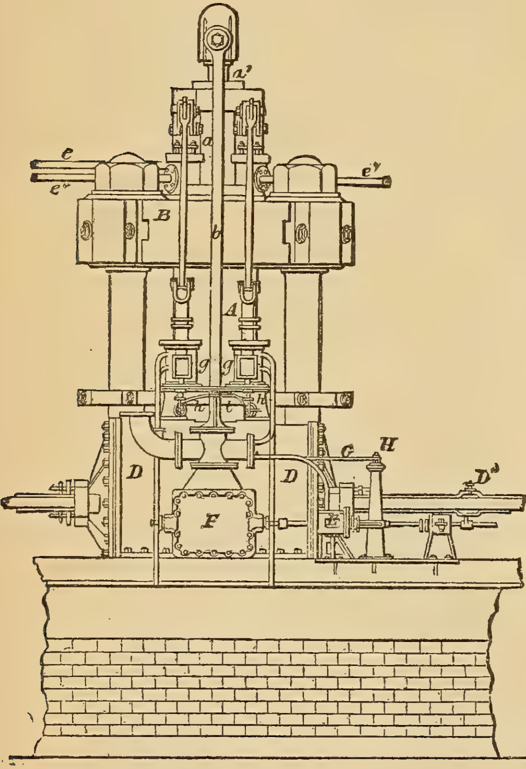
72.



the lower movable table on which is attached the annular ring, on which in the first place the plate was placed till adjusted and securely held by the movable table. The ring, travelling up, catches the projecting edges of the plates to be flanged, and bends them accurately over the die. The valves of both the main and small cylinders are then opened to the exhaust. The large one falls very rapidly, owing to the weight of its parts, and the plate just flanged thus comes off the die immediately before it has had time to contract on it. One valve works all the four small, and another the large cylinder.

A variety of irregular shapes can be produced by this machine, such as locomotive fire-box ends and front tube-plates with reverse flanges, and it is stated the saving amounts to fully two-thirds of cost by hand. This is without taking into consideration the economy in being able to use plates of an inferior quality in place of high-class brands, which may be only necessary because the commoner, but equally strong kinds, would not stand the fire and working; but there is the additional saving in cost in the fitting together afterwards, in saving of fuel, and wear and tear of furnace. A $\frac{5}{8}$-in.

73.



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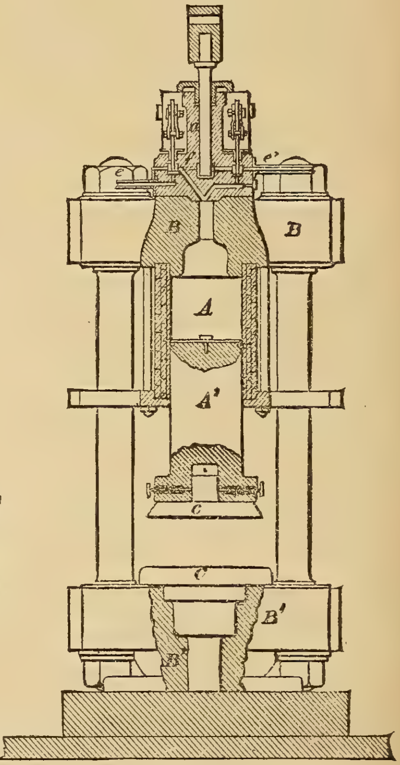
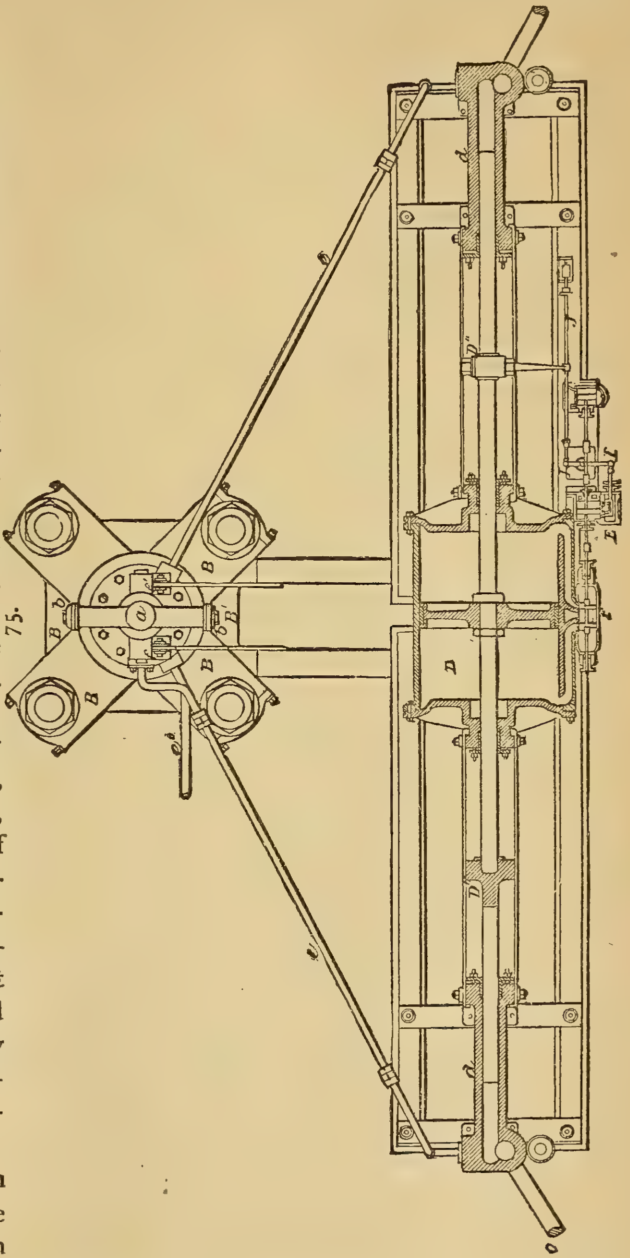


thickness of plate and 7 ft. diameter can have a 4½-in. or 6-in. flange put on all round in a little over 30 seconds. The only limit to the machine's performance a day is the furnace power which can be placed round it.

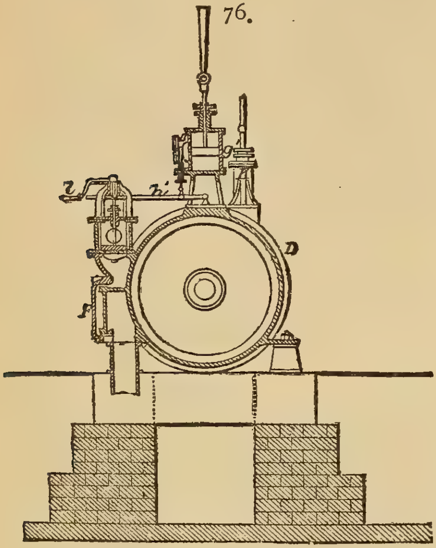


75

Similar results are obtained by the use of the presses devised by Haswell of Vienna which are illustrated in Figs. 72 to 77. The pumps are worked by a horizontal direct-acting steam cylinder, of large size, the working of which is directed by an automatic arrangement, so that it is perfectly and instantaneously under the control of the driver.

Fig. 72 is an end view of the press and steam engine. Fig. 73 a side elevation. Fig. 74 is a vertical section. Fig.

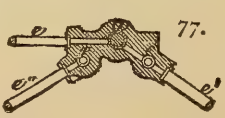
75 a horizontal sectional plan. Fig. 76 a cross-section of the steam and cushion cylinders. Fig. 77 a horizontal section, through the chambers of the regulating valves of the press, and the attachment of the water pipes.


76.

The press consists mainly of two vertical cylinders A and *a*, of different sizes. These are fixed to a large cast-iron frame B, of cruciform shape, supported on four malleable-iron columns, firmly secured to a bed plate B′. The two pistons A′ and *a*′ have cross heads fitted on their outer ends, connected at their extremities by two strong malleable-iron side rods *b*, so that the pistons work simultaneously. These rods, passing through grooves formed in the upper frame B, and the intermediate steadying frame B″ act likewise as guides to prevent the rams turning.

The hammer is fitted to the lower end of the pressing ram A′, and the bottom anvil bedded to the bottom bed-plate B′. The main steam cylinder D is fixed horizontally on a strong bed-plate, the piston rod passing through packed stuffing boxes at both ends, to which are attached, in the same line and plane, the rams of the respective hydraulic pumps.

A small steam cylinder E is placed by the side of the main steam cylinder to work its slide valve. Attached to the valve rod of this steam cylinder E, by the lever I, is a tappet rod J, which is worked automatically by a projecting arm attached to the crosshead D″ of the ram of the pump *d*′, this acting upon the slide valve of the small cylinder E, which in its turn actuates the slide valve F of the main cylinder D, which works the pumps of *d* and *d*′.


77.

The discharge branches of the two pumps *d* and *d*′ are connected by the pipes *e* and *e*′ with the passages and chambers formed as in Fig. 77. The inlet and discharge regulating valves *f* and *f′*, are worked by levers L L, having rods attached to their free ends, and directly connected with the piston rods of the two small auxiliary steam cylinders *g* and *g′*. The slide valves of these auxiliary cylinders are controlled by means of the hand leaders *h* and *h*.

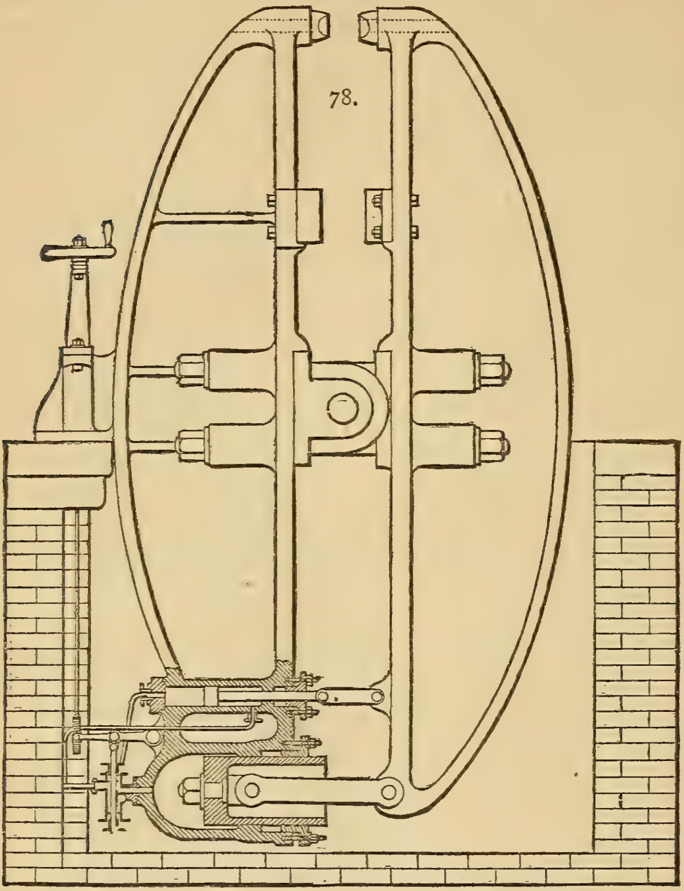
The small cylinders K are charged with oil, and have perforated pistons, the rods of which are also connected to the regulating valve levers L L. These relieve the sudden shock incident to the work put upon the levers. There is also a loaded safety valve, not shown, placed in a convenient position on the pressure pipe, for relief in case of need.

The press may be worked at any desired pressure, regulated by the boiler steam pressure, and either a light or heavy blow, or squeeze, can be given to suit the work in hand. The velocity or number of strokes a minute, depends upon the efficient action and rapidity with which the two auxiliary cylinders *g* and *g′* can be worked, as these regulate the inlet and escape valves *f* and *f′*, the driver having merely to handle the levers *h* and *h′* of the slide valves. No expensive foundations are required, as both the engine and press are self-contained.

The slabs swaged by this press are always hammered to some extent before being put into the mould, and similarly to all special tools, Haswell's press can only be used at a pecuniary advantage for work in which there is repetition. In such cases the saving is very great, as for instance with locomotive cranks and wheels, it may amount to as much as 50 per cent., and even more, as compared with forgings finished under the hammer.

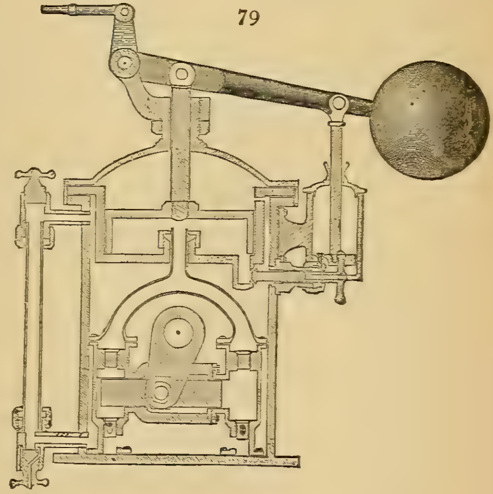
McKay and Macgeorge's 60-ton hydraulic riveting machine, Fig. 78, consists chiefly of two levers, each 12 ft. long, the left-hand lever being stationary, and carrying the hydraulic cylinders, whilst the other turns upon a centre and advances or withdraws the dies from the work. In consequence of the levers being of so large a radius, the arc described by the end of the movable one is for all practical purposes a straight line, and no inconvenience results from the obvious theoretical objection that the movable die travels in the arc of a circle. Both cylinders and working parts are quite out of the way, being placed beneath the ground within a pit, which is carefully closed, and so protected from frost, as well as from danger of injury, accidental or otherwise. Guarding against frost is a very great consideration, as hydraulic cylinders are often left full and become liable to burst through their contents freezing in winter.

The machine is actuated by turning the starting handle and so giving motion to a slide valve of peculiar construction, which, at its highest position, allows free communication between both hydraulic cylinders and the exhaust; a slight movement downwards connects the accumulator with the bottom of the piston of the small cylinder, which is of sufficient area to overcome the friction of the packing of both cylinders, and friction and inertia of levers, and thus the dies are brought quickly up to their work, whilst from the elevated exhaust cistern, water flows in behind the ram of the larger cylinder, thus effecting a material economy in the quantity of water required to be supplied under pressure.



The valve is next moved lower, allowing full accumulator pressure to come upon the larger ram, which in this particular machine transfers to the dies a pressure of 60 tons. After a slight pause, which is necessary to cool the rivet, the hand-wheel is reversed and the slide valve returned to its highest position, thus allowing the cylinders to empty themselves, whilst a constant pressure on the annular area of the small piston always draws the levers back, and the attendants make ready another rivet, and alter the position of the boiler shell under operation. The depth of gap is 5 ft. 3 in., which is found to be sufficient for ordinary boiler work, but this length can be increased. When not required for riveting, this machine is used for the purpose of bending or straightening ships' beams and girders whilst cold, an application of value. The straightening or bending jaws are placed midway between the centre and the riveting dies, and if necessary a pressure of 120 tons can thus be brought to bear upon a beam or girder placed between them. Moreover, they can be adjusted so as to take in any depth of beam, and as they do not interfere with the employment of the machine for riveting, they are as well fitted for occasional as for constant use.

In connection with direct acting steam pumps, Mason's Hydraulic Governor, Fig. 79, is well worthy of notice. In few, if any, of the so-called Direct Acting Steam Pumps is a rotary motion developed by means of which an ordinary revolving governor can be operated. It therefore becomes necessary to resort to some other method. To overcome this difficulty a Hydraulic Governor has been invented, the motion of which is obtained by a vibrating arm attached to some reciprocating part of the pump or engine to be governed.



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The Governor consists mainly of a cylindrical shell or reservoir, which contains therein a small pair of single-acting regulating pumps, connected with and actuated by some reciprocating part of the pump or engine, so that each stroke of the regulating pumps is in unison with the strokes of the main engine, the duty of the regulating pumps being to force a liquid contained within the reservoir into a chamber and under a weighted piston, which is connected, as will be seen, by suitable mechanism, to the throttle valve of the pump or engine to be controlled. The chamber containing the piston is provided with an outlet passage and a regulating valve, which returns the liquid back to the reservoir to be pumped over again. By this arrangement when the liquid is forced into the chamber more rapidly than it is intended to be by the normal operation of the engine, such as would be the case were the load to be suddenly removed, or a variation of steam pressure to take place, the escape passage being uniform the liquid will enter the chamber faster than it escapes, and will consequently act on the piston, moving it in such a manner as to close the throttle valve and thus reduce the speed. Any decrease in speed would have a reverse action of the piston, the setting down of which supplies more steam to the engine, the size of the outlet passage from the chamber being adjusted by the regulating valve. It will thus be seen that the engine can be regulated with great nicety during every portion of every stroke.

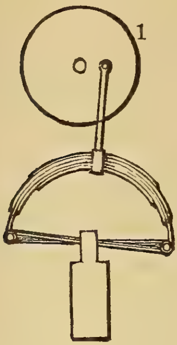
The small cylinder seen at one side of the reservoir near the top, is filled with oil or other liquid, and fitted with a piston which connects with the weighted lever. This piston is provided with a small opening which allows the oil to pass from one side to the other as it rises and falls; the duty of which is to prevent sudden or irregular movement of all connected parts. On the opposite side of the reservoir is placed a glass gauge, so that the height of liquid can be readily seen at all times. The top of the glass is provided with a screw plug for the purpose of filling the reservoir. The bottom is also provided with a small drip valve, so that the oil can readily be drawn off in case of repairs, &c. This useful invention is the property of The Mason Hydraulic Co. of Boston, Mass.

HAMMERS.

The term power hammer is generally applied to those hammers in which the power is applied by means of a belt or gearing; and is used to distinguish them from the ordinary steam hammer, in which the hammer block is attached to the piston rod of the engine; and it thus includes all varieties of friction, crank, and trip hammers.

The oldest form of power hammer is that known as the helve, trip, or tilt hammer, the construction of which was evidently suggested by the common hand hammer. It consists of a stout helve of timber bound with iron bands, to preserve it from splitting under the violent concussions to which it is subjected. This helve is supported by trunnions, working in plummer blocks, which are bolted to a strong foundation of timber, the said trunnions forming the fulcrum upon which the lever turns. To one end of this lever is attached the hammer head, and at the opposite or back end revolves a wheel provided with a series of cams, by the action of which the lever is depressed and the hammer head raised. The chief disadvantages attending the use of trip hammers are, the difficulty of connecting them with the driving power, especially where a number of hammers have to be driven from one shaft. The head and die of a trip hammer, weighing, together with the irons for attaching them 100 lb., and perhaps more, will make, with a helve 8 ft. long, from two to three hundred blows a minute. This motion far exceeds anything that could be attained by a direct reciprocating motion given to the hammer head by a crank, and is also greatly in excess of any rate of speed that would be assumed from theoretical inferences. The hammer helve being of wood possesses a certain amount of elasticity, and acts like a vibrating spring, its vibrations being in unison with the speed of the tripping points; and it is upon this principle of elasticity that the whole machine must be constructed, in which respect it stands as an exception to almost every other known machine; even the framing for supporting the trunnions, which without experience one would suppose required to be made as rigid as possible, is found in practice to answer best when composed of timber, this timber being disposed in such a manner as to allow it to spring and yield. The sudden and varied resistances that are offered to line shafts which drive trip hammers, tend to loosen couplings, destroy gearings, and produce strains that are unknown in other cases; shafting arranged with the usual proportions for transmitting power, soon failing if applied to drive trip hammers, and consequently all rigid connections, or metal attachments, are inadmissible, belts arranged so as to have their tension varied at will being the usual means employed for transmitting power to trip hammers, and the only one that has been successful. Further, there being no means of varying the height to which the hammer head is raised, and this head acting only through the force of gravity, the power of the blows delivered by any given hammer, must always remain constant upon a given thickness of metal; the only variation in power being in the wrong direction, that is the thicker the mass of metal being operated upon, the less powerful will be the blow delivered by the hammer, while the opposite conditions are almost always required. Again, from the fact of the hammer head moving in an arc of a circle, of which the trunnions form the centre, it follows that only when operating upon pieces of a certain thickness will the hammer deliver a flat blow, and this want of parallelism will increase, in proportion to the thickness of the mass being operated upon, those parts of the metal which are nearer to the fulcrum being unduly compressed, while the more distant portion will receive scarcely any blow. Another difficulty attending the use of trip hammers, is the rapidity with which crystallization takes place, in the attachments for holding the die blocks to the helves, where no elastic medium can be interposed to break the concussion of the dies; bolts to pass through the helve, even when made from the most fibrous Swedish iron, not lasting on an average for more than ten days, and often breaking in a single day; the safest mode of attaching the die block, and the one most generally employed, is to forge it solid, with a band to surround the end of the helve.

Another class of power hammers consists of those which are operated by means of a crank, the connection between which and the hammer head consists either of some kind of deflecting spring, or of an air cylinder, and to this class therefore belong all the various forms of pneumatic hammers. The great advantage possessed by these hammers over the older helve, consists in the fact that the blow delivered by the tup always remains parallel to the face of the work, no matter how much the latter may vary in thickness; while at the same time, they generally possess some arrangement by means of which the power of the blow may be varied, to suit the constantly changing requirements of the work operated upon.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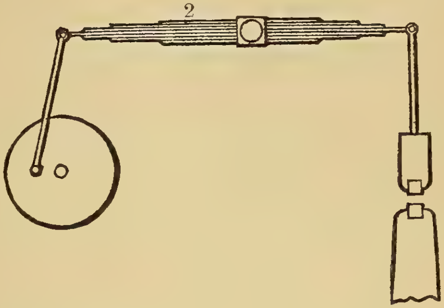
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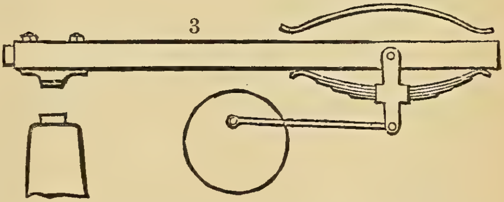
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In Fig. 1 is shown a diagram of an arrangement of crank hammer having a curved leaf spring interposed between the crank and hammer, the latter being connected to the spring by means of a leather strap, the link being rigidly fixed to the spring. The appearance of the device in motion will not recommend it, but the effect produced, so long as the various parts last, is all that can be desired. A diagram of a later introduced arrangement is shown in Fig. 2, which judged by the test of endurance and non-liability to derangement appears to be the best, of all those hammers constructed on this principle, which have up to the present time been introduced. The pivot is fixed on the frame, and the vibration produced by the crank is multiplied at the other end of the spring lever, so that strong, rapid blows are given by the hammer. In Fig. 3 is shown a kind of composite machine, half trip hammer, half crank hammer. The helve and radial die movement are retained, but the hammer is operated by a crank, through what is in substance an elastic connection. Such hammers as these here described are well adapted for light work and small pieces, as on account of the light weight of the reciprocating parts they can be driven at very high speeds; but, as is the case with all hammers having a fixed range of movement and fixed anvils, the intensity of the blows diminishes as the thickness of the work increases, which, as already pointed out, is the reverse of what is required. This objection is increased or diminished according as the length or range of stroke is long or short; and when the parallelism of the dies changes also with the thickness of a piece, as in the system of construction shown in Fig. 3. We must therefore conclude that, for general purposes, considerable effect must be sacrificed in attaining rapid blows in the manner here explained; while a dead blow, or stop motion, which is almost indispensable in most kinds of work, would not be at all easy to apply in the case of a hammer operated by springs.

The two earliest inventions for steam hammers were those of James Watt, in 1784, and of William Deverell in 1806; but it was not until about the year 1843 that the first steam hammer was made at the Bridgewater Foundry by James Nasmyth, who had taken out a patent for the same in 1842; and though this was far from being the perfect machine which we are now accustomed to see, its erection marked the commencement of a new era in the history of the iron trade, for without the possession of this valuable invention it would have been simply impossible to execute the gigantic forgings of the present day. A steam hammer is in its main features an extremely simple machine, one of the principal problems in connection with its manufacture being how best to resist the destructive effects resulting from the concussion of its blows. It therefore follows from this that weighty economical reasons exist for separating into detail, as much as possible, whatever is liable to break; but there is also another reason for this, which applies especially to power-driven hammers. Joints, however firmly they may be bolted together, still impart some elasticity, and however suitable cast iron may be for the framing of most kinds of machines, it is, as is well known, wanting in that elasticity which hammer frames seem to require. It is not assumed that joints when rigidly bolted together can impart much elasticity, but if the frame of a hammer be cast in one piece, or even as was formerly sometimes done, the cylinder cast solid with the framing, it is at once obvious that the liability to fracture will be considerably increased. In watching the course of practice in steam hammer construction, there are certain plans which, for details such as valve gearing, are gradually becoming general; of these the pendulous swing bar operating by sliding on the hammer head is one of the principal. The reason for this is obvious enough at the present time, when it is known how difficult it is to maintain any positive connection with a hammer head; a link, lever, or tappets, or any device to which the shock of the blows is imparted soon giving way; but a swing bar, bearing lightly against the hammer block, and nearly in the plane of motion, is but little affected by the concussion.

John Richards, in his treatise on the 'Principles of Shop Manipulation,' when treating of steam hammers, gives the following particulars of the principles of their construction and operation:

"The direct application of steam to forging hammers is beyond question the greatest improvement that has ever been made in forging machinery; not only has it simplified the operations that were carried on before its invention, but it has added many branches, and extended the art of forging, to purposes that never could have been attained except by the steam hammer.

"In forming a conception of steam hammers we must not fall into the common error of regarding them as distinct machines, or as operating on new principles. A steam hammer is nothing more than the common hammer driven by a new medium, a hammer that receives power through the medium of steam, instead of by belts, shafts, and cranks. The steam hammer supplies other purposes besides transmitting power, and seems to be so perfectly adapted to fill the different conditions of power hammering that there seems nothing left to be desired; for it will be seen that steam as a driving medium for hammers fulfils the following conditions:

1. "The power is connected to the hammer by means of the least possible mechanism, consisting only of a cylinder, a piston, a slide valve, induction pipe, and throttle valve; these few details taking the place of a steam engine, shafts, belts, tension pulleys, cranks and springs, with pulleys, gearing, and all details that are required between the hammer head and the steam boiler in other cases.

2. "The steam establishes the greatest possible elasticity in the connection between the hammer and the power, and at the same time cushions the blow at both the top and bottom of the stroke, or on the top only, as the case may require.

3. "Each blow given is an independent operation, and can be repeated at will, while in other hammers such changes can only be made throughout a series of blows by gradually increasing or diminishing their force.

4. "There is no direct connection between the moving parts of the hammer and the framing, except the lateral guides for the hammer head; the steam being interposed as a cushion in the line of action, reduces the required strength and height

of the framing to a minimum, and avoids positive strain and concussion.

5. "The range and power of the blows, as well as their time, are controlled at will; this is the greatest distinction between steam and other hammers, and the particular advantage that has led to their extended use.

6. "The power is transmitted to the hammers through a small pipe, that may be carried in any direction and for almost any distance at a very small expense, so that the hammers may be placed in such positions as will best accommodate the work, without reference to shafts or other machinery.

7. "There is no waste of power by slipping belts or other frictional contrivances to graduate motion; and finally there is no machinery to be kept in motion when the hammer is not at work.

"One thing more remains to be noticed, namely the valve motions, which are a matter of some intricacy, but without which all that has been explained would fail to give a proper idea of steam hammer action.

"Steam hammers are divided into two classes, one class having the valves moved by hand, and the other, automatic valve movement. The action of the automatic hammers are again divided into what is termed the elastic blow, and the dead blow. In working with elastic blows the steam piston is cushioned at both the up and down stroke, and the action of the hammer corresponds to that of a helve trip hammer, the steam filling the office of a vibrating spring; the hammer gives a quick rebounding blow, the momentum being only in part spent upon the work, and partly arrested by the cushioning of steam in the bottom of the cylinder under the piston. Aside from the greater rapidity with which a hammer may operate when working on this principle, there is nothing gained and much lost; and as this kind of action is imperative in any hammer that has a maintained connection between its reciprocating parts and the valve, it is perhaps fair to infer that the reason why most automatic hammers act with an elastic blow is either from a want of knowledge as to a proper valve arrangement, or because of mechanical difficulties in arranging valve gear.

"In working with dead blows no steam is admitted under the piston until the hammer has finished its down stroke, and expended its momentum upon the work. So different is the effect of these two plans of operating, that on most kinds of work a 50-lb. hammer working with dead blows will perform the same duty that one of 100 lb. will when acting with elastic or cushioned blows. This difference between the dead and elastic stroke is so important that it has served to keep the hand-moved valves in use in many cases, where much could be gained by automatic hammers that had the same functions. Some of the makers of steam hammers have now so perfected the automatic class that they may be instantly changed, so as to work with either the dead blow or the elastic blow at pleasure, thereby combining all the advantages of both principles. This brings the steam hammer where it is hard to imagine a want of further improvement.

" The valve gear of automatic steam hammers to fill the two conditions of allowing a dead or an elastic blow, furnishes one of the most interesting examples of mechanical combination. It was stated that to give a dead or stamp stroke, the valve must move and admit steam beneath the piston after the hammer has made the blow, and stopped on the work, and that such a movement of the valve could not be imparted by any maintained connection between the hammer head and valve. This problem is met by connecting the drop or hammer head with mechanism that will by reason of its momentum continue to move after the hammer head stops. This mechanism may consist of various devices. Massey in England, and Ferris and Miles in America, employ a swinging wiper bar that is, by reason of its weight or inertia, retarded and does not follow the head closely on the down stroke, but swings into contact and opens the valve after the hammer has come to a full stop. By holding this wiper bar continuously in contact with the hammer-drop, elastic or rebounding blows are given, and by adding weight in certain positions to the wiper bar, its motion is so retarded that the hammer will act as a stamp or drop. A German firm employs the concussion of the blow to disengage the valve gear and effect this after movement of the valves in steam hammers. Other makers effect the same end by employing the momentum of the valve itself, by having it connected to the drop by a slotted or yielding connection, that allows to a certain extent an independent movement of the valve.

" Another principle to be noticed in connection with hammer action in forging processes is that of the inertia of the piece operated upon, a matter of no little importance in the heavier class of work. When a piece is placed on an anvil and struck on the top side with a force of one ton, the bottom or anvil side of the piece does not receive an equal force; a share of the blow is absorbed by the inertia of the piece, and the effect on the bottom side is, theoretically, directly as the force of the blow, less the inertia of the piece acted upon. In practice this difference of effect on the top and the bottom, or between the anvil and the hammer sides of the iron, is much greater than would be supposed. The yielding of the soft metal on the top cushions the blow, and protects the under side from the force; this, because the effect produced in striking a piece of heated iron is by no means to be measured by the force of the blow. It requires, to use a technical term, a certain amount of force to "start" the iron, and anything less than this force has but little effect in starting the particles and changing the form of the piece. From this it can be seen that there must occur a great loss of power, for whatever force is absorbed by the weight of the piece produces no effect. By watching a smith using a hand hammer it will be seen that whenever the piece operated upon is heavier than the hammer, but little, if any, effect is produced on the anvil or bottom surface. Nor is this loss of effect the only one. The cost of heating, which generally exceeds the cost of shaping, is directly as the amount of shaping that may be done at each heat; and consequently if the two sides of a piece, instead of one, can be equally acted upon in shaping, one half the heating will be saved. Another consideration to be gained by equal action on both sides of large pieces is the quality of the forgings produced, which is generally improved by the rapidity of the shaping processes, and injured by too frequent heating. This loss of effect by the inertia of the piece acted upon being as the relative weight of the hammer and the piece, it follows that the loss increases with the weight of the work; not only the loss of power, but the cost of heating, which also increases with the size of the work. There is such a difference in the mechanical conditions between light and heavy forging that for any but heavy work there would be more lost than gained in attempting to evade or remedy this loss of effect on the anvil face of the work.

"To remedy this defect in heavy forging, John Ramsbottom designed what may be termed compound hammers, consisting of two independent heads or rams moving in opposite directions, and acting simultaneously upon the work which is held between them. These hammers were a departure from all modes of forging that had ever been practised to the time, and constituted an original invention;

one that has fully attested its value in actual service at Crewe, where such hammers have been at work for several years.

"It will seem probable that the arrangement of these double-acting hammers is necessarily complicated and expensive, but the contrary is the fact. The rams are simply two masses of iron mounted on wheels that run on tracks like a truck, and the impact of each hammer, so far as not absorbed in the work, is neutralized by the other. No shock or jar is communicated to framing or foundation, as in the case of single hammers that have fixed anvils. The same rule applies in the back stroke of the hammers, as the links that move them are connected together at the centre, where the power is applied at right angles to the line of the hammer movement. The links connecting the two hammers constitute, in effect, a toggle joint, the steam piston being attached when the links meet in the centre. The steam cylinder is set at some depth in the earth below the plane upon which the hammers move, and even when the heaviest work is done there is no perceptible jar to be felt when standing near the hammers, as there always is with those that have vertical movement and are single acting."

Besides the classes already mentioned, steam hammers are divided into single and double-acting hammers. In the single-acting hammers the steam is only employed to raise the tup or hammer head, which is then allowed to fall freely by its own weight; and the force of the blow struck is therefore only equal to the power developed by the given weight falling from the given height. In the double-acting hammers the steam is employed to accelerate the descent of the falling mass, as well as to raise the same; and as by this means the rapidity of the descent may be made to equal double that due to the action of gravity, and as the force of the blow struck by a falling mass increases as the square of the velocity, it follows that the power of a given hammer may by this means be increased three or four-fold; that is to say, a 5-ton hammer may be made to do work equal to that of a 15 or 20 ton single-acting hammer. Many hammers are now constructed to be used either as single or double-acting, at the will of the operator.

Fig. 4 is of a single standard 20-cwt. Rigby hammer by Davis and Primrose of Leith. This hammer is double-acting, the cylinder C being 19 in. diameter with a stroke of 42 in. The piston with the piston rod P are forged in one piece from the best scrap iron, the lower end of the rod being enlarged and formed with a dovetail slot to receive the hammer face H which is made of steel. In consequence of this formation of the piston and rod it is necessary to make the stuffing box and gland of the cylinder in halves. The former is a tube of metal made to fit the interior of the cylinder and having a flange on the lower end by which it is bolted to the cylinder flange. The gland is of the usual kind, and the halves are held together by plates and bolts of malleable iron. The piston is fitted with Ramsbottom rings of steel. The valve V, which is a piston valve of wrought iron working in a brass-lined chamber, is shown in section in Fig. 5, the lining *l* is pierced with holes opposite the ports for the passage of the steam. The steam enters the middle of the valve at *o*, between the two pistons, and according as the valve is moved up or down the steam enters the top or bottom of the cylinder, and exhausts by the ends of the valve, a passage *p* connecting the lower and upper ends of the chamber C to take away the exhaust steam from the lower part. Connected to the valve spindle is a safety trigger T, the object of

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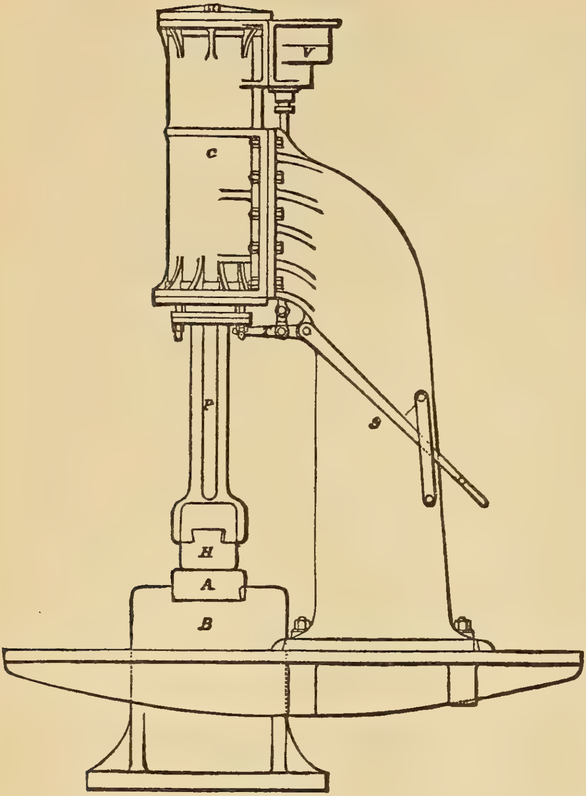

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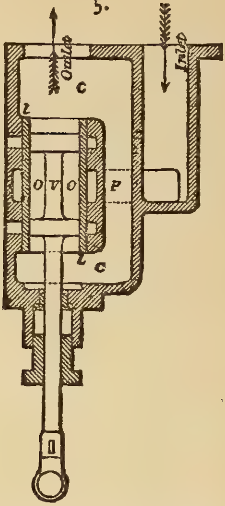

which is to prevent the piston from striking the upper end of the cylinder. When the hammer rises beyond a certain point the enlarged end of the piston rod strikes this trigger and raises the valve, thereby admitting steam to the top of the cylinder, exhausting from the bottom, and so reversing the motion of the hammer. In this hammer the weight of the moving parts, piston, piston rod, and tup, is a little over 20 cwt. The total weight of the hammer is about 18 tons, of which the anvil block weighs about six tons. The diameter of the piston rod is 9⅜ in., and it is flattened on two opposite sides, the neck of stuffing box and the gland being similarly flattened, in order to prevent the piston from turning round when working. Generally in this style of hammer the area of the bottom side of the piston is about three-fourths of that of the top side. The

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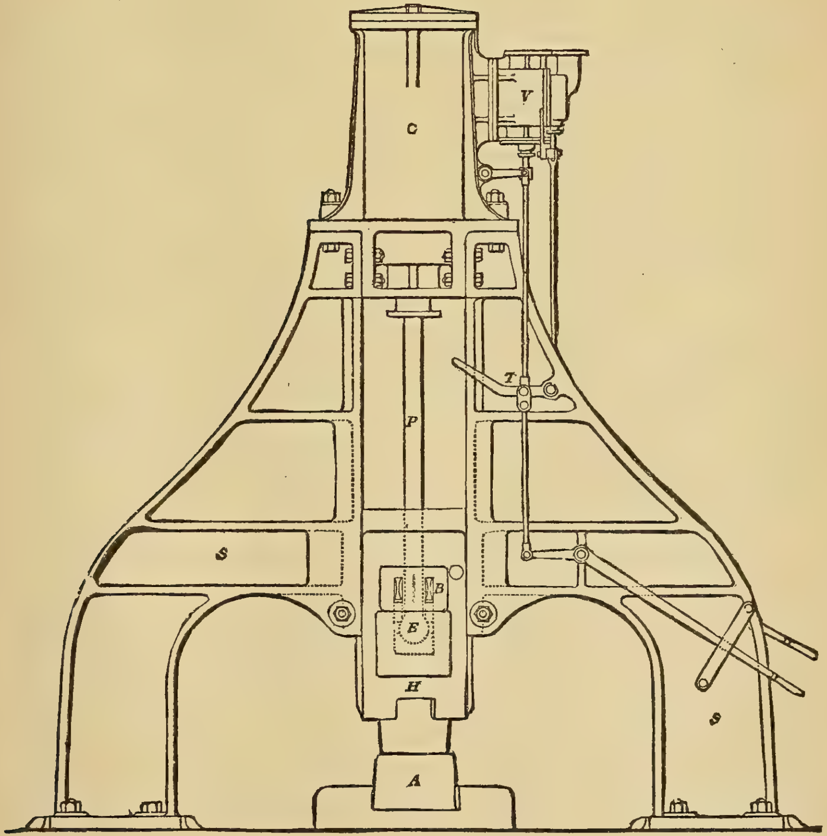
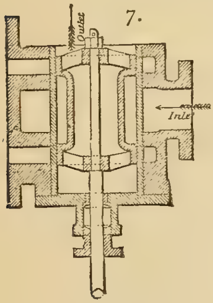


pressure of steam used varies from about 35 lb. to 60 or 70 lb. on the square inch. These hammers are also made with double standards, the standards being of box section and placed 12 feet apart at the ground level. The total weight of a double standard 3-ton hammer of this class, having a cylinder 25 in. in diameter and 5 ft. stroke, is about 46 tons, of which the anvil block weighs about 18 tons.

In Fig. 6 is a 3-ton hammer made by Davis and Primrose, in which the standards are made so as to form guides for the hammer head. The cylinder C is 22 in. in diameter with a 4-ft. stroke; the valve being similar to that in Fig. 5. The framing S is of H section, except for very heavy hammers, when it is made either of box section in cast iron, or of wrought iron. The piston and rod are forged in one piece from the best scrap iron; the piston being fitted with Ramsbottom rings of steel. The lower end of the rod is enlarged into a spherical form, as shown in dot at E, and into the tup is inserted a suitable cup to fit the spherical end of rod. The rod is held in its place in the tup by a cap B, formed in halves, which is hollowed out to fit the spherical end and is fixed by cotters. This arrangement provides against the side strains which are so frequently produced in the working of a steam hammer, as the tup can yield a little without unduly straining the piston rod.

Fig. 7 is a section of the valve employed by Davis and Primrose for their self-acting hammers. This valve is of brass and hollow; it has two pistons. The steam entering at the middle of the valve, between the two pistons, as in the hand worked hammers, the exhaust from the under side of piston passing through the interior of the valve to the discharge pipe placed on the top. The self-acting motion is given by a suspension lever L of a curved form, which is kept in contact with the hammer face T, as in Fig. 8. The tup T as it rises pushes this lever to one side and causes the valve to rise until the lower port opens to the exhaust and the upper port to the steam, when the hammer descends, and the valve then moves in a downward direction.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A double, single, and self-acting 10-cwt. steam hammer by Fawcett and Firth of Leeds, is shown in front elevation in Fig. 9. The hammer is firmly bolted to a stone foundation; the anvil block B resting upon a distinct support, the upper part consisting of a double layer of balks which form an elastic cushion between the foundation and the anvil block. The weight of the anvil block is 5 tons, the

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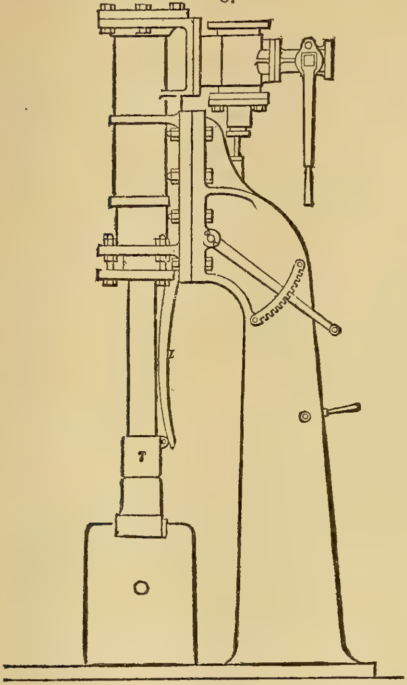

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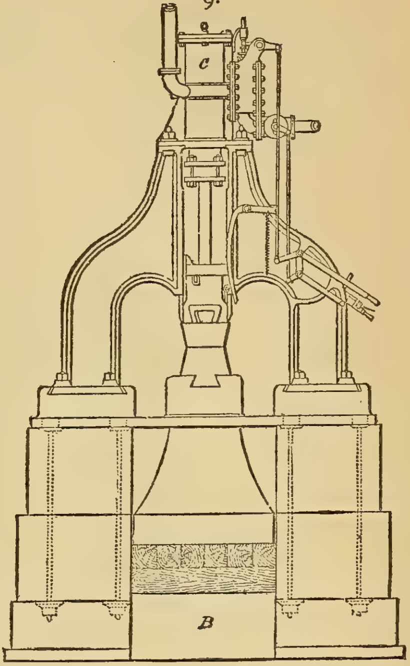

total weight of the hammer, including the block, being 14·5 tons. The diameter of the cylinder C is 11½ in., and the full stroke of the piston 2 ft. The weight of the moving parts, 10 cwt., gives a total of 2240 units of work, which is equal to the force exerted by a weight of 1 ton falling through a height of 1 ft.; but by admitting the steam to the top side of the piston, and so accelerating its descent, the force of this blow may be considerably increased.

This hammer is so proportioned in the various parts, that all are equally strong, and in order to facilitate the carrying out of any necessary repairs the parts are made as accessible as possible; the repairing of a steam hammer generally occasioning considerable expenditure on account of the complex nature of its details, and the difficulty of getting at the various parts. One of the most important parts of all steam hammers is the valve, which is generally coupled direct and worked by hand, and it is therefore necessary that pressure and friction should be as much as possible avoided; with a view to fulfilling these requirements, and at the same time rendering it easy to compensate for wear in either the valve or the cylinder face, the form adopted in this hammer consists of an equilibrium valve of a double V or square section, Figs. 10 to 14: Fig. 10 is a sectional plan on the line *e f*; Fig. 11, a sectional elevation on the line *a b*; Fig, 12, a similar section on the line *c d*; and Figs. 13, 14, are a front view and section of a portion of the cylinder face showing the position of the ports, the central ports being the exhaust. This valve slides in a corresponding V face in the cylinder, and in a V jacket, by which the back part of the valve is enclosed; thus the only parts which are exposed to the pressure of the steam in the steam chest are the two ends; and as the areas of these are equal, the friction is reduced to a minimum. This form of valve admits of any wear, being easily adjusted; as in order to follow this up it is only necessary to plane up the jacket faces at H.

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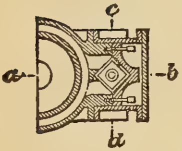

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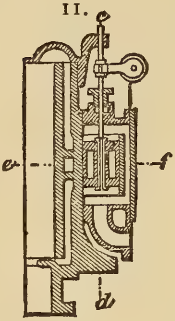

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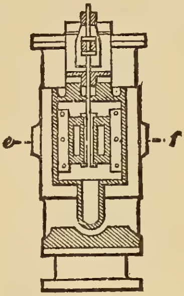

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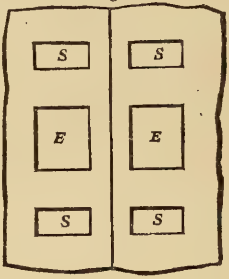

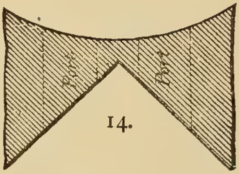

14.

These hammers are made in various sizes, both as single and double standard hammers; and are either double and single acting, with dead blow by hand lever; or single and double acting worked by hand. In the former the valve is made without lap; in the latter lap is added to get the single action, and the valve travels more to get the double action, or steam at the top of the piston. The sizes of the single standard hammers range from ½ cwt. to 10 cwt.; and the double standard from 10 cwt. to 3 tons.

In Fig. 15 is shown a 1500 kilo. steam hammer of German design. The framework of this hammer consists of two hollow wrought-iron standards S, slightly tapering, resting upon cast-iron

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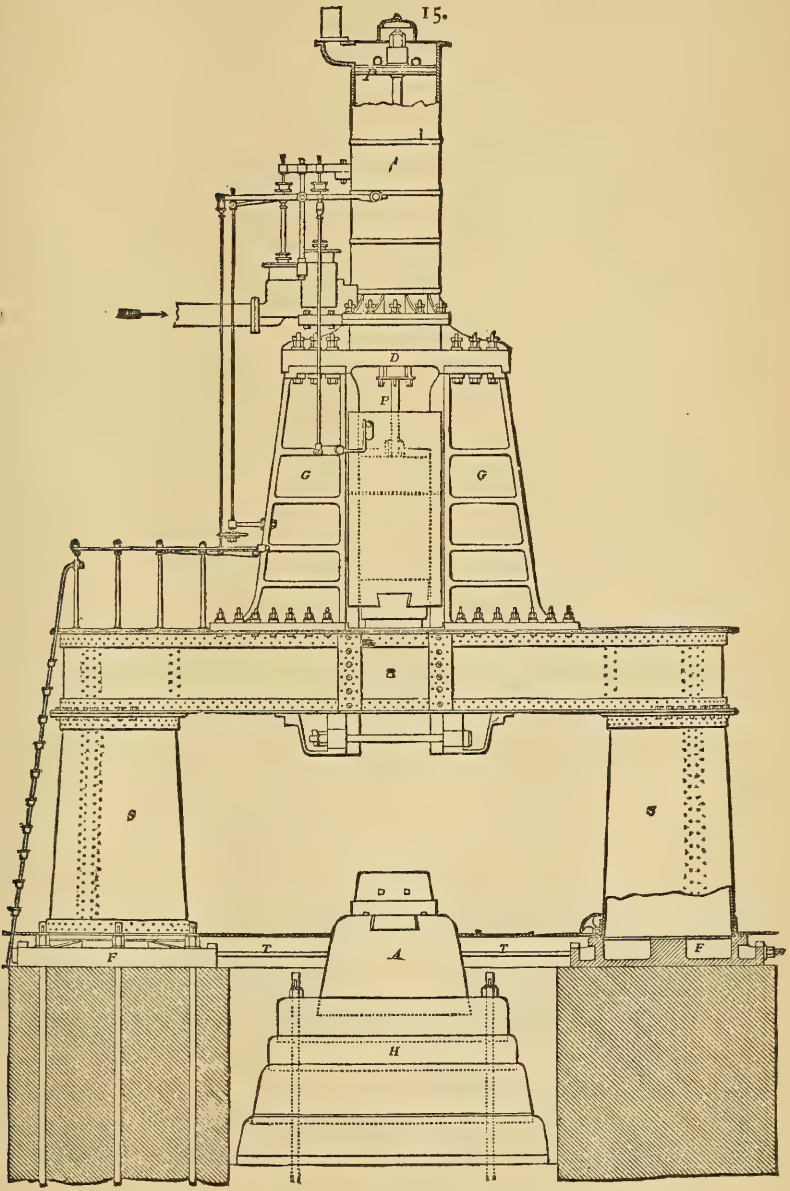

bed plates F, which are held together by tie-rods T. These standards support a wrought-iron girder B, 3 ft. 1 in. in depth, on the top of which are bolted the cast-iron standards G, to which the bed plate D is bolted; this latter carries the cylinder C. The height of these standards with the bed plate is 9 ft. 9 in. The standards G, besides being firmly fixed to B by a number of bolts, also abut firmly against the covering plates of the girder, so that any lateral movement in the standards would necessitate the shearing of all the rivets which pass through the plates. The distance between the standards S, centre to centre, is 20 ft. 7 in., their height 8 ft. 6 in., and their mean diameter about 5 ft. The total height from the ground level to the top of the bed plate D is 21 ft. The diameter of the cylinder C is 3 ft. 7¼ in., and the full stroke of the piston 8 ft. 3 in. The piston and piston rod P are made of the best crucible cast steel; the weight of the piston, piston rod, and tup being 14·75 tons, and this multiplied by the full stroke of the piston gives 272,580 units of work, equal to the power exerted by a weight of 121·6 tons falling from a height of 1 foot. The anvil block H is cast in four layers, and is firmly bolted to a separate foundation; the diameter of the bottom layer of this block is 12 ft., and the top layer 8 ft. 9 in., the height of the anvil A being 3 ft. 10 in. The weight of each of the wrought-iron columns S is 2 tons 9¼ cwt., the bed plates F, 6 tons 17¾ cwt., the girder B, 6 tons 8 cwt., each of the cast-iron standards G, 14 tons 5½ cwt., the bed plate D 5 tons 8¼ cwt., and the cylinder C, 4 tons 18½ cwt.; the total weight of the whole structure, including the piston and tup, but excluding the anvil A and block H, being 86 tons 2¼ cwt.

In Fig. 16 is shown a front elevation of the 35-ton steam hammer erected at Woolwich Arsenal in 1873. As this hammer is double acting, it can be rendered equal to a single-acting hammer having four times the length of stroke, or 42 ft., or to the same stroke with four times the weight, namely 140 tons, or about equal to a 150-ton single-acting hammer with a 10-ft. stroke. The standards S are of the ordinary H section, and are bolted to cast iron box girders G bedded in concrete, these standards and girders being independent of the foundations of the anvil. The distance between the standards S is about 19 ft.; the height from the ground line to the top of the cylinder 45 ft.; and there is a clear height for forging purposes of 11 ft. The diameter of the cylinder C is 54 in., with a full stroke of 10 ft. 6 in. From the great weight and length of this cylinder, it was thought probable that if it were held only by the bottom flange, the vibrations caused by the violent concussions when the hammer is at work would crack the cylinder close to the bottom flange, an

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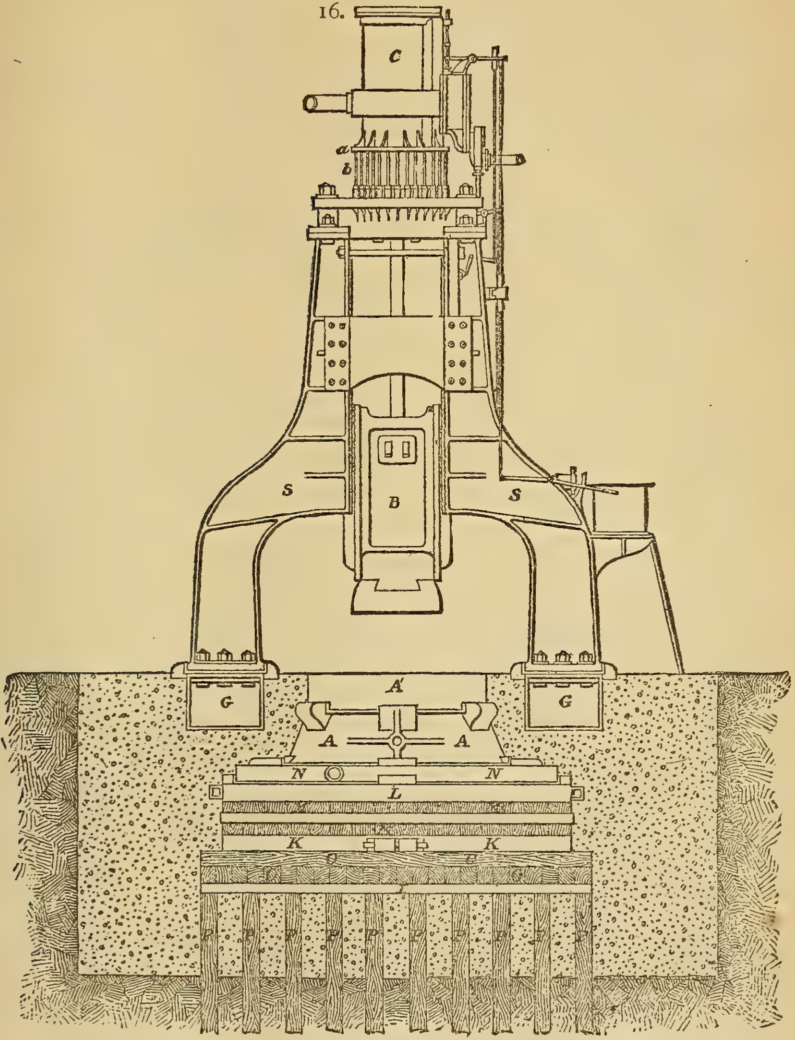

accident which has happened with smaller hammers; there is therefore provided a second flange *a*, at some distance from the bottom of the cylinder, and the long bolts *b*, from the entablature to this second flange, give a certain amount of elasticity to absorb the vibration. The valve is one of Wilson's balance valves, which is easily managed by one man, and can be regulated so as to admit the steam at the top of the piston or not, at the will of the attendant. The weight of the falling mass is 35 tons, the full length of fall being, as stated above, 10 ft. 6 in.; and in the hammer block B there is formed a well for the purpose of adjusting the distance of the block from the piston in the cylinder C, by which means the full amount of stroke can always be obtained, whatever may be the thickness of the work operated upon.

The ground upon which this hammer has been erected was at one time marsh land, and a large expenditure was necessary in order to secure a foundation which would be sufficiently solid, and at the same time elastic enough to withstand the impact of so great a mass. For this purpose the ground was excavated to a depth of nearly 20 ft. for a space of 42 ft. square, and in the centre of this hole one hundred piles P were driven in rows of ten, forming a square of 30 ft. on the side. These piles having been driven as far as they would go, were cut off level at a height of about 4 ft. 6 in. above the bottom of the hole; and the hole was then filled in with concrete up to the level of the tops of these piles. Upon the top of this was laid a cast-iron plate I, 30 ft. square and 11 in. thick, weighing 164 tons; this plate was cast in three pieces, for the purpose of rendering it less liable to accidents in transit. On the top of the plate I are two layers of oak balks, 12 in. square, upon which is a second cast-iron plate K, cast in two pieces, which weighs 121 tons, and is 27 ft. square by 11 in. thick. Upon this plate are oak balks M, 2 ft. long, placed on end, and fitted accurately together to form a solid mass, and which are held together by bands of iron 6 in. broad and 2 in. thick. On these timbers is placed a third plate L, 24 ft. square and 12 in. thick, also cast in halves, and weighing 120 tons. Upon this is placed a thin layer of timber and felt, in order to fill up any inequalities or to make up for any want of flatness in the castings; and then comes a fourth plate N, 22 feet square, 12 in. thick, and weighing 100 tons, which is cast in one solid piece. Upon the plate N is placed the anvil block A, which is a frustum of a cone 15 ft. in diameter at the base, 12 ft. diameter at the top, and weighing 103 tons; and upon this is placed the anvil A′, weighing 70 tons. It will thus be seen that the weight of cast iron in this foundation is nearly equal to 700 tons. The whole of the space around the foundation is filled in with concrete.

In Figs. 17 to 20 is shown the 8000 kilogramme steam hammer erected by Schneider of Creusot, which is the largest steam hammer in existence. Fig. 17 is a front elevation, and section through the foundations; Fig. 18 is a side elevation; and Figs. 19, 20, show the method employed for connecting the tup to the hammer block. The foundation for this hammer was excavated to a depth of about 36 ft. The first portion of the foundation consists of a mass of

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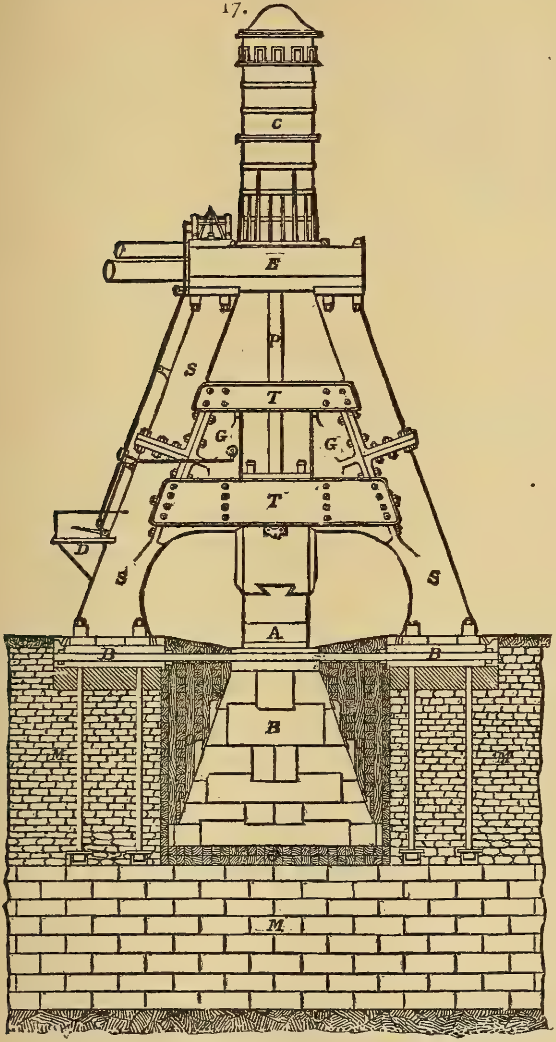

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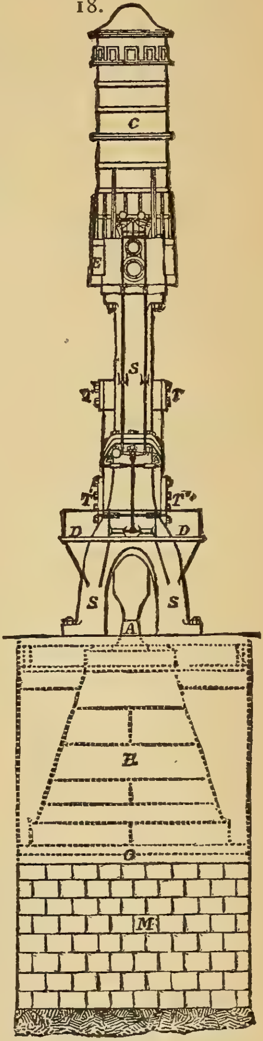

masonry in cement M, 13 ft. in thickness, and containing upwards of 785 cubic yards; on the top of this masonry is laid a bed of oak planks, O, 3 ft. 3 in. thick, to form an elastic cushion or seat for the anvil block B. This block is of cast iron, and consists of six layers, each of the layers, with the exception of the top one, on which the anvil A rests, being cast in two pieces; it is 18 ft. 4 in. in height, its area at the base being 355·2 sq. ft., and at the top 75·3 sq. ft.; the total weight of the anvil and block being 736 tons 12 cwt. It will be seen that the anvil block rests upon the foundation entirely independent of the main supports of the hammer, the space between the foundations of the latter and the sides of the block being filled in with oak planking, as shown at O, Fig. 17. The main supports S are rectangular in section; they are cast hollow, each one being formed in two pieces, and bolted together in the manner shown in the figures; they rest at the base on massive cast-iron bed plates B, to which they are keyed, the bed-plates resting on the masonry M surrounding the anvil block. The guides G are cast separately, and are bolted to the supports S, as in Fig. 17, the whole being firmly held together by the wrought-iron bracing plates T, which weigh 24·5 tons. The height of the main supports S is 33 ft. 7 in., and their weight, including the guides G, 245·5 tons. On the top of the standards S is fixed the entablature E, which supports the cylinder C, and this entablature weighs 29·5 tons. The cylinder C is made in two lengths, each 8 ft. 2 in. in height, the two parts being united by bolts; the internal diameter of the cylinder is 6 ft. 3 in., and the piston rod P 14 in. in diameter, the cylinder with its cover weighing 21·6 tons. The distribution of the steam within the cylinder is effected by means of two single equilibrium valves, the diameter of the admission valve being 13½ in., and that of the discharging valve 18 in.; these valves are operated by means of rods and levers, which are brought down to within the reach of an attendant standing upon the platform D, which is fixed at about 10 ft. above the level of the floor, and which affords a protection from the heat of the forging. The area of the under side of the piston, deducting that of the piston rod, is 4238 sq. in., which gives, with a pressure of 71 lb. per sq. in., a total lifting force of 134 tons. The

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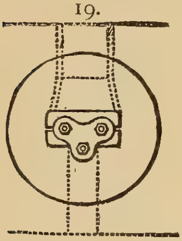

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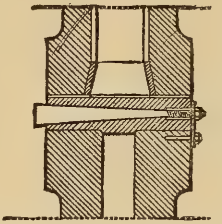

weight of the falling mass, including piston, rod, tup, and all moving parts, is 79 tons, and this multiplied by the full stroke of the piston, namely 16 ft. 5 in., gives a total of 2,886,400 units of work, which is equal to the force exerted by a weight of 1247 tons falling through a height of 1 ft. The width between the supports S is 23 ft. 9 in., and the clear height under the lower connecting plates T is 10 ft. 6 in., so that there is ample room for the manipulation of the largest masses with which the hammer may have to deal. The clear width between the tup guides G is 6 ft. 3 in. The height of this hammer from the bed plates B to the top of the cylinder C is 61 ft., and the height of the anvil block 18 ft. 4 in., which gives for the whole structure, including the thickness of the masonry foundation, a total height of over 92 ft. Notwithstanding this great height,

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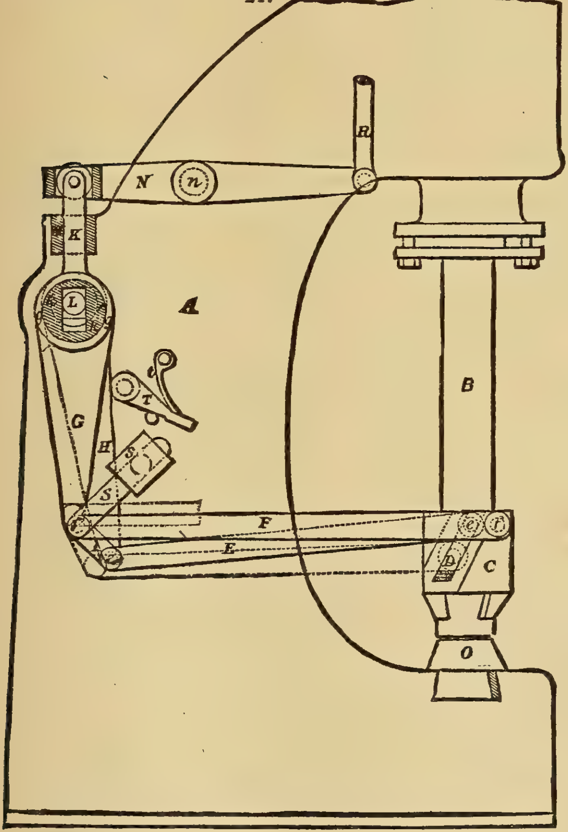

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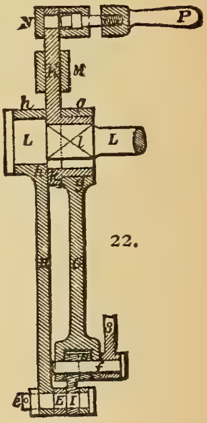

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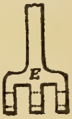

23.

which naturally tends to reduce the stability of the hammer, the whole has been so well proportioned, and the oak cushion beneath the anvil block acts with such efficiency, that rigidity has been secured, and the vibratory shock at a given distance is less severe than with many smaller hammers. The total weight of the whole of the parts from the bottom of the bed plates B to the top of the cylinder, including the moving parts and all parts necessary to the mechanism, is 520 tons 18 cwt., and this added to the weight of the anvil and block, namely 736 tons 12 cwt., gives a total weight of 1257·5 tons for the whole structure.

Sturgeon's valve gear for steam hammers is shown in Figs. 21 to 23. Fig. 21 is a partial side elevation of a steam hammer indicating the position of, and the manner of connecting the valve levers; and Fig. 22 is a vertical section through the levers. The gear renders the valve self-acting and regulating, so that it may adapt itself to all variations in the stroke caused by the varying thickness of the masses of metal upon which the hammer is required to operate. For this purpose the valve gear which is employed for reversing the valve for the up stroke, follows the hammer throughout the whole of its stroke, so as to be always in a proper position for reversing at the moment when the hammer strikes the object placed beneath it, the necessary motion being given to the valve by means of the jerk caused by the impact of the hammer. A is the hammer frame or standard, B the piston rod, and C the tup. In one of the sides of the tup C a slot D is formed to receive the stud *e* at the end of the link E, and to the same face of the tup the link F is connected by means of the stud *f*. The link E, at the end *e'*, is connected to the lever H, having a boss *h* working upon the plain part of the stud L. The lever H and the links E and F are all connected, by means of the short elbow link I, to a second lever G, as in Fig. 22; Fig. 23 being a plan of the end of link E. The lever G is arranged so as to move through an arc and at the same time to admit of an up and down movement on its fulcrum L. Through the centre of the boss *g* passes a second boss *k* having a slot cut in it in order to allow an up and down motion upon the square part *l* of the stud L; the boss *k* being steadied and guided in its movement by the stem K working through the guide M. To the upper end of the stem K is connected the rocking lever N, working upon the centre *n*, and to the opposite end of this lever the valve rod R is connected. When the hammer strikes the object on the anvil O, the shock caused by the impact forces the stud *e* forward in the slot D to the position shown by the dotted lines. This motion of the stud *e* and link E raises the lever G and stem K, and so depressing the valve rod R and reversing the valve; the hammer then commences its up stroke and continues to rise until, by the motion of the links and levers E F G H,

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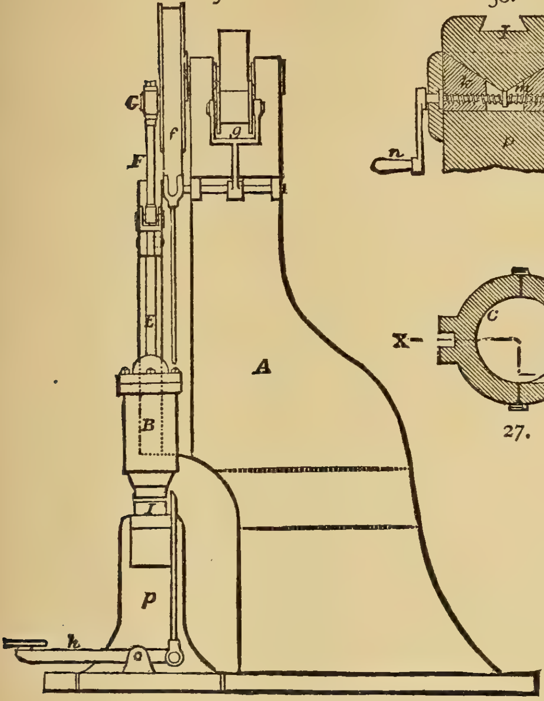

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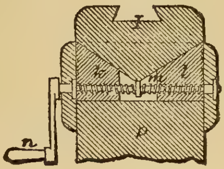

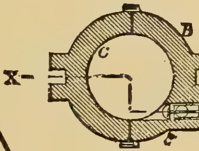

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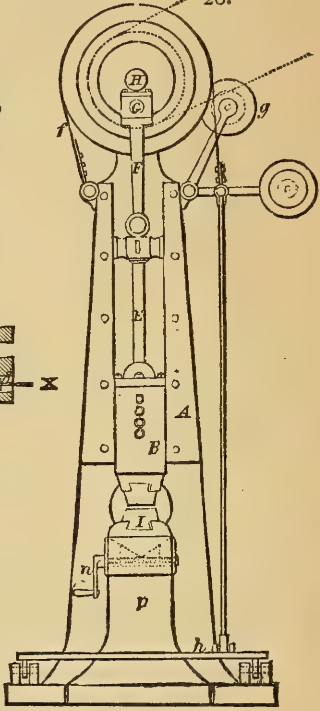

the end of the rod S working through the guide *s*, is brought into contact with the stop T, this forces down the lever G and raises the stud *e* to its former position, thus again reversing the valve and causing the hammer to descend. The stop T is held in position and caused to act upon the rod S by the spring *t*; and this arrangement allows the stop to accommodate itself sufficiently to the slight additional upward motion of the hammer which takes place after the reversing of the valve, such motion being due to the *vis viva* of the moving mass. In hammers having only a short stroke the stop T is fixed, but when it is requisite that the hammer shall admit of variations in the height of fall the stop is carried on an adjustable plate. When it is required to work the valve by hand or strike a dead blow, it is necessary to disconnect the rocking lever N from the other parts of the motion by drawing out the handle P, and thus allowing the stem K to work through the slot in the rocking lever N, Figs. 22 and 24. In this case also the stud *e* may be tightened in the slot D by means of a bolt.

Sholl's atmospheric hammer, Figs. 25 to 30. Fig. 27 is a horizontal section through the cylinder or tup B; and Fig. 28 is a vertical section of the same on the line *x x*. In this hammer the striking part B consists of a cylinder C with a piston D which is connected by means of the piston rod E and connecting rod F to the crank pin G; the cylinder C being filled with compressed air which forms an elastic connection between the striking part and the power by which it is operated. C is lined with lignum-vitæ or some other slow conductor of heat, in order that the heat generated by the compression of the air in the cylinder may not be communicated to the adjacent parts, and to prevent injury to the packing leathers of the stuffing box and piston; for similar reasons the piston D is made of the same non-conducting material. One of the principal features in this hammer consists in the stuffing-box leathers *a* and cylinder leathers *a'*; these are so arranged that the pressure of the air within C tends to force them into contact with the surface of the cylinder and of the piston rod, and by these means a perfectly air-tight joint is at all times secured. Fig. 29 is of an alternative method of fitting the packing leathers *a* and *a'*; annular recesses are turned in the face of the piston and of the cylinder cover which are free to communicate with the interior of the cylinder by means of a number of small apertures *c* and *c'*; the compressed air passes through these apertures and so forces the leathers *a* and *a'* against the surface of the cylinder and of the piston rod. In the side of the cylinder C is formed an air-tight passage *d* which, by means of the valves *e* placed at the top and bottom, communicates with the interior; in the side of the cylinder are also formed a number of small apertures *b* which are opened and closed by valves. These valves may be opened or

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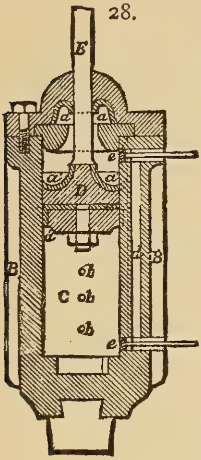

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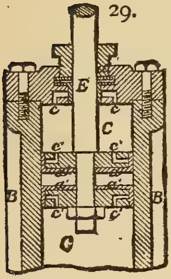

closed at pleasure, and are arranged to be actuated by the cylinder in its reciprocating motion, their object being to regulate the force of the blow struck by the hammer. The driving power is a belt, its action being regulated by means of the steel friction brake *f*, which is actuated simultaneously with the belt tightener by the treadle *h*; and by this arrangement the hammer may be made to deliver blows with any desired force or rapidity, or to give a dead blow. In conjunction with this hammer, a special construction of anvil, Fig. 30, is employed. The anvil block I can be raised or lowered at pleasure by means of the wedge pieces *k* and *l*, which are caused to approach or recede from each other by the right and left handed screw *m*. The principal object of this arrangement is to allow of the hammer delivering any number of light blows with great rapidity.

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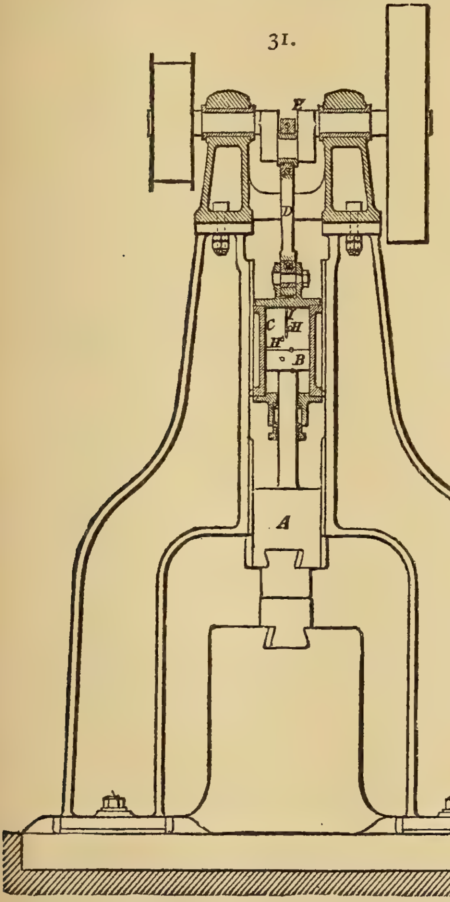

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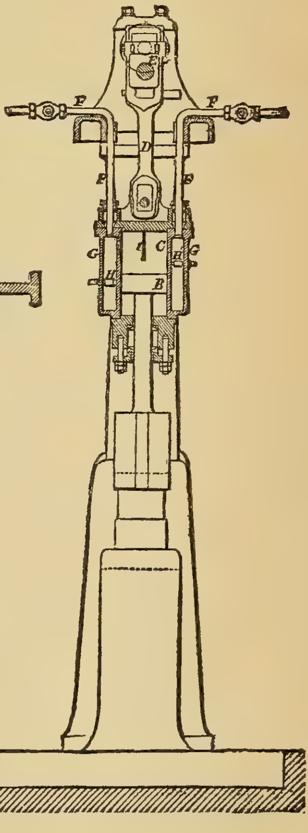

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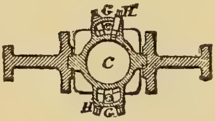
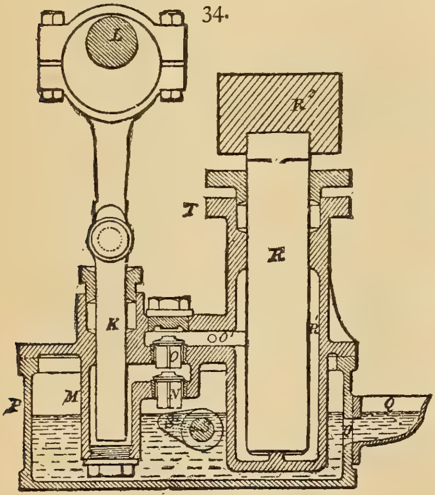


David Davy's power hammer, Figs. 31 to 33. Fig. 31 is a front elevation partially in section, Fig. 32 is a vertical cross section, and Fig. 33 a horizontal section through the cylinder C and framing. In general structural appearance this hammer is very similar to the ordinary pneumatic hammer; the tup A being attached to a piston B working in a cylinder C, connected to a crank shaft E, from which it receives its motion in the usual way. The construction of the cylinder, however, differs considerably from others. In pneumatic hammers as usually constructed the air is admitted to the cylinder C at atmospheric pressure, the compression above and beneath the piston necessary to raise the hammer and to accelerate its fall, being effected within the cylinder itself, and consequently the construction of a very powerful hammer on this principle is almost impracticable on account of the large capacity which would be required in the cylinder; but in this hammer the air is introduced into the cylinder at a higher pressure than that of the atmosphere, and increased according to the power required. Steam may be employed to take the place of compressed air in the cylinder C, but in that case provision must be made for carrying off the water of condensation. It is claimed for this hammer that by supplying the air to the cylinder C at a pressure exceeding that of the atmosphere, the power of the hammer is increased to a corresponding degree; and that consequently under this system very powerful hammers may be constructed without increasing the dimensions of the cylinder C as would otherwise be required. On each side of C is a pipe F for conveying the compressed air from the accumulator R, Fig. 34, to its interior; the portions F′ of these pipes are parallel to the sides of the cylinder C, and pass through stuffing boxes at the top of the chambers G situate on each side; the cylinder in its reciprocating motion slides up and down the pipes F′, and so maintains a constant connection between the supply pipes F and chambers G. The chambers



34.

G communicate with the interior of the cylinder C by means of the holes H which are placed so as to be immediately above and below the piston B, when the latter is at the centre of its stroke; and these holes are fitted with screw plugs H′ by which any of them may be closed, in order to regulate the amount of extra compression which shall take place in the cylinder C in the ordinary way. On the inside of the cylinder C there are longitudinal relief channels I for the purpose of allowing the compressed air to pass from the upper to the lower side of the piston B, when the latter passes beyond the ends of the channels, and so to restore the equilibrium within C. Fig. 34 is a section through the apparatus employed for supplying the compressed air to the cylinder C. The cylinder of the air pump M, with its suction and delivery valves N O, are placed within the closed chamber P, which is filled with water to above the level of the opening Q, the water being poured into the cistern at the siphon trap Q′, through which also is drawn the supply of air to the suction valve N; the object of this arrangement being to purify and cool the air before compressing it. The bottom of the accumulator chamber R′ is also made to dip into the water in the cistern P for the purpose of keeping cool the compressed air contained therein. The accumulator ram R is loaded with weights in the usual way in order to obtain the required pressure within the chamber R′ and cylinder C. The pump plunger K is worked from an eccentric on the shaft L. To obviate the necessity for stopping the plunger K each time that the accumulator cylinder is sufficiently charged, the following means are adopted. A rocking shaft S is mounted in the cistern P, and is provided with a cam or lever arm S′ so placed as to be capable of lifting the suction valve N off its seat and supporting it in that position. One end of the shaft S is prolonged through the side of the cistern P, and is provided with a lever arm and a connecting rod T, thus causing the shaft S to revolve and the cam S′ to raise the suction valve N from its seat, so that the plunger K will continue to oscillate without supplying any air to the accumulator R′. Directly the quantity of air within the accumulator R′ is reduced and the ram R descends, the rod T will drop and allow the cam S′ and valve N to return to their former positions, and the pump will again commence to deliver air to the accumulator R′.

Longworth's pneumatic hammer, of which Figs. 35 and 36 are front and side elevations, is so complicated in the details of its construction, that it is very questionable if it can afford satisfactory results in working, as among so much complication of parts there must of necessity be liability to derangement; at the same time the manner of constructing the cylinder, which does away with the necessity for the use of packing, must be an improvement of much practical value if found to work satisfactorily. The peculiarities in the construction, and the manner of actuating this hammer will, however, be readily understood from the following description. The horizontal shaft A is provided with fast and loose pulleys *a a′*, and is driven by a belt. The shaft A for a portion of its length is made square in section, and on this square part the two cams B and C are loosely fitted, so as to partake of the rotary motion of the shaft, and at the same time be free to slide upon it. On the shaft E, which is parallel to A, is fixed the rocking lever D, and to this a reciprocating motion is given by the action of the cams B and C upon the rollers *b* and *c*, these rollers being fixed to D; and this motion of the rocking lever is communicated to the hammer F, the cam B acting upon the roller *b* lifting the hammer, while its downward

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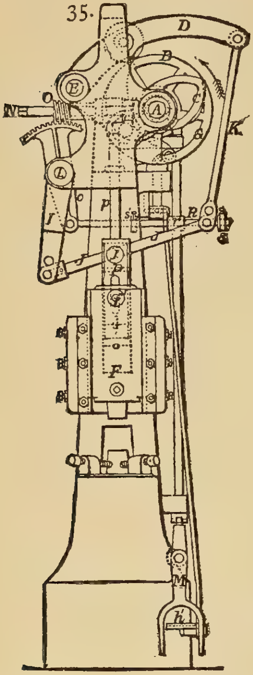

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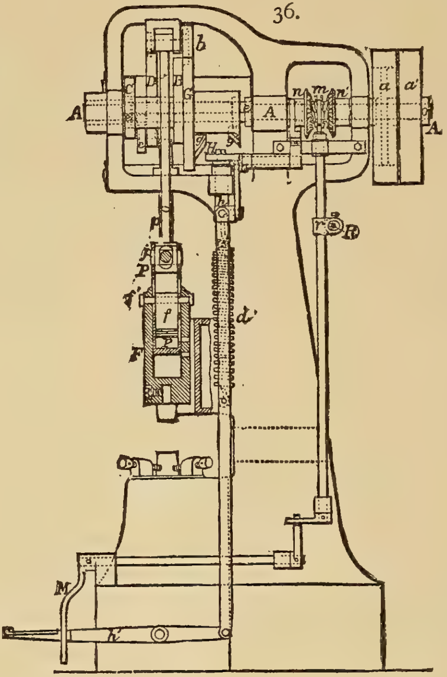

stroke is accelerated by the action of the cam C upon the roller *c*. In order to do away with the necessity for packing glands to the air cylinder of the tup, the same is constructed as in the section, Fig. 36. The main or outer cylinder F, which forms the tup, slides in V-shaped guides in the framing of the machine, and has working in it the piston P, this being formed with an internal cylinder to receive the secondary piston *f*, this latter piston being attached to the main hammer F by a pin *f′* which passes through slots in the piston P; through the upper part of the piston P passes the pin *j*, which forms with the lever J the means of connection between the rocking lever D and hammer F; and into the top of the piston P is screwed a guide rod *p*, which works through a part of the framing. The action of these pistons and cylinders is as follows:—When the piston P is forced down, a cushion of compressed air is formed between the bottom of it and the interior of the main cylinder F; and when the piston P is raised a similar cushion is formed between its interior and the bottom of the piston *f*; the air for this purpose entering through holes or ports formed in the side of the main cylinder F, Fig. 36. To the boss of the rising cam B is fixed a circular disc G, the radius of which is equal to the largest radius of the rising cam. When the hammer is required to remain at rest, the disc G is in the position in Fig. 36, when it supports the roller *b*, and with it the rocking shaft D, the shaft A revolving without imparting any motion to the rocking lever. On the side of the disc G there is an inclined cam *g*, and on the boss of the disc a similar cam *g′*; these cams are situate in different planes, and are inclined in opposite directions. Below the shaft A and between the cams *g g′* is a horizontal disengaging roller H mounted upon a vertical rod *h*, which is connected to the foot lever *h′*; the roller H being held in its normal or depressed position by means of the spring *d*, the lower end of which is connected to the framing, and its upper end to the rod *h*. By pressing down the lever *h′* the roller H is brought into the plane of the cam *g′*, and by its action causes the cams B C and disc G, with their connecting bosses, to slide upon A towards the right hand, which brings the cams B and C into the planes of the rollers *b* and *c*. The rotation of the shaft A will now cause B and C alternately to depress and raise the hammer; and this action will continue so long as the lever *h′* is held down, so that a single blow or any number of blows may be struck by the hammer as required. Directly the lever *h′* is released the spring *d* draws down the roller

H into the plane of the cam *g*, the action of the roller upon the cam *g* causing the cams B and C and the disc G to slide in the contrary direction, or toward the left hand, which brings the various parts into the position Fig. 36; and so arrests the motion of the hammer by the action of the disc G. Upon the shaft A are two collars *e e′*, which fit into recesses formed in the bosses of the cams B C, and act as air pistons to check the momentum of the cams when sliding on the shaft for the purpose of putting the hammer in or out of gear; there is also an arrangement, shown in Fig. 36, for preventing the roller H from being forced out of the plane of the inclined cams *g g′* while acting upon them. The distance to which the hammer is raised or depressed, and consequently the force of the blow, is controlled and regulated as follows. The connection between the rocking lever D and hammer F is formed by means of the lever J, which is circular in cross section; and this lever slides freely through the pin *j*, in the upper part of the piston *p*. One end of the lever J is connected to the rocking lever D by the connecting rod K, and the opposite end is pivoted on a movable fulcrum on the hanging arm L, which is fixed to a sector shaft *l* carried by the main framing; and according as this fulcrum is moved to the right or left hand, relative to the connecting pin *j*, a greater or less movement will be given to the hammer F. To control the movement of this fulcrum, a forked lever M is connected by a series of shafts and levers to a clutch *m* on the shaft A; the clutch being so connected to the shaft as to revolve with it, and at the same time being free to slide upon it. The clutch *m* is situate between two bevel wheels *n n′*, mounted loosely on A, each of these wheels being formed with a clutch on its surface. The wheels *n n′* both gear with a pinion on the shaft N carrying a worm O which gears into a toothed sector *o* on the sector shaft *l*. When the forked lever M is moved to the right or to the left the clutch *m* is brought into driving contact with one or other of the bevel wheels *n n′*, causing the shaft N and worm O to revolve, and so moving the sector *o* and sector shaft *l*, to which is fixed the arm L; this, according as the sector is moved in the one direction or the other, increases or decreases the length of the lever J on the side K, thereby increasing or shortening the distance through which the hammer F is raised and lowered, and so causing a heavy or light blow to be struck as required. To the lower arm of the toothed sector *o* is pivoted a rod R sliding freely in the guide *r*, and carrying two adjustable stop-collars *s s′*. When the toothed sector *o* is moved in either direction the collar *s* or *s′* comes in contact with the arm *r* on the clutch shaft, and throws the clutch *m* out of gear with the bevel pinion *o* or *p* as the case may be, and prevents any further motion of the arm L. The connecting rod K and the fulcrum arm L are each provided with more than one hole, so that the hammer F can be raised or lowered bodily, to admit of greater variation in the thickness of the work operated upon.

Fig. 37 is a side elevation of Butterfield's atmospheric hammer. The main frame of the hammer G is provided at the top with plummer blocks to support the journals *b* of the hammer beam B, of which Fig. 38 is a plan. This beam is of cast iron, in one piece, in the form of a truss, having a central longitudinal web *x* with flanges and ribs *y z* on each side of it; the journals *b* being situate at about midway of its length. To the forward end of the beam B is attached the hammer A, which is connected to the hammer beam by the forked rod end *e*. Between the cross-head F and cups 3, Figs. 41, 42, are fitted solid indiarubber cushions F′; these cushions are provided with a central hole to allow of the passage of the rod 4, and they are finally held at a proper tension between the cross-head and the cups by means of a tightening nut screwing upon the rod 4. The cushions F′ allow to the hammer A an easy movement, preventing shock and concussion, and relieving the hammer rod from much of the resistance due to the rebound. In the circular loop *h* at the back end of the beam B is suspended the air cylinder

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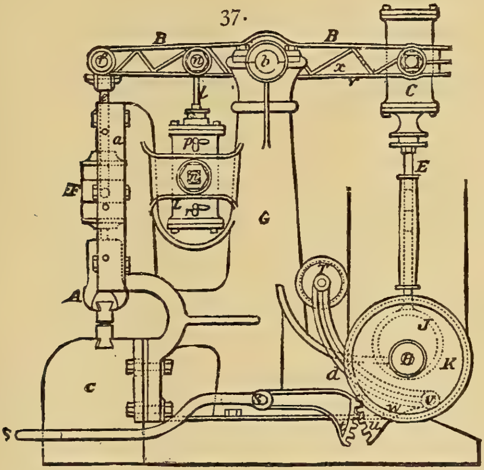
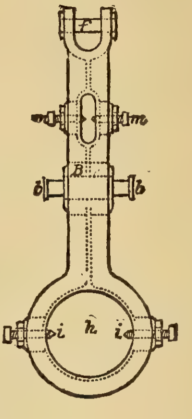


38.



C, Fig. 37, which is free to oscillate upon the screws *i* by which it is supported. C is closed at both ends, the piston rod E passes through a stuffing box, and is connected to the rod of the eccentric J. In the side, at about midway of its length, there is a small hole forming a communication between the external air and the interior of the cylinder. The eccentric J is made with a central slot to allow of its being adjusted to give a greater or less throw, in order to obtain any required length of stroke of the piston D; and this eccentric after being adjusted is firmly secured upon the shaft H by means of a nut turning upon the shaft and a set screw passing through the collar, as in the section Fig. 39. Between the hammer A and main standard G is suspended the supplemental cylinder L, shown in section Fig. 40, the piston rod *l* is connected to the hammer beam by means of the centre screws *m*, the cylinder itself being so suspended on its centres *n* as to be free to oscillate backwards and forwards in conformity with the up and down motion of the beam B. The diameter of the cylinder L is less than that of the cylinder C; and the length or thickness of the piston P is nearly equal to half the length of the interior of the cylinder. In the side of L, and about midway of its length, are two small holes *q*, forming a communication between the external air and the interior of the cylinder; and at the top and bottom of the cylinder, and communicating with the interior, are two cocks *p* and *v*. This hammer is constructed to be driven by the power obtained from a belt applied to the pulley K, on the shaft of which is fixed the eccentric J; the shaft H being supported in plummer blocks which are fixed to the projecting arm *d* of the main framing G. The treadle S and tightener T are for starting, stopping and regulating the speed of the hammer. The treadle S, Fig. 37, is pivoted upon pins which are fixed in the sides of the framing; on the side where the belt pulley K is fixed the end of this treadle has a segmental rack *t* gearing into a similar rack *u* on the front of the tightener arm U, pivoted upon the pin *v*, which is fixed in the side of the arm *d*; on the under side of this arm is a projecting shoe *w*,

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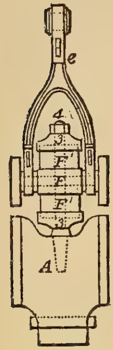

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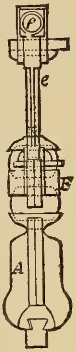

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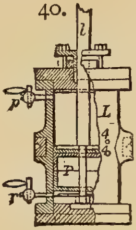

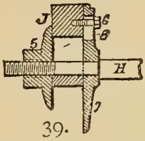

39.

which extends within the rim of the pulley K, and this shoe, when the treadle is released and the tightener falls away from the belt, acts as a brake upon the pulley, and so arrests the motion of the driving shaft H; on the opposite side of the framing the end *t'* of the treadle S is formed to act simply as a counterweight. The cylinder C with its attachments is constructed to equal the weight of the hammer A and its attachments, thus balancing the beam B upon its journals *b*; and, consequently, the power required to work this hammer is small, being only so much as is necessary to overcome the inertia and friction of the parts.

When the piston D, by the revolution of the eccentric J, is caused to descend, the compression of the air in the lower part of the cylinder C commences immediately that the piston has passed the opening *k*, and directly the power developed by this compression is sufficient to overcome the inertia and friction of the moving parts the cylinder C is drawn down, and the hammer A begins to rise; when the eccentric arrives at the bottom of its throw, and the movement of the piston is reversed, the hammer A will continue to rise under the combined influence of the power developed by the expansion of the air in the bottom of the cylinder C and the momentum which it has acquired from the downward stroke of the piston, until the power developed by the compression of the air in the upper portion of the cylinder is sufficient to overcome these two forces, when the hammer will be driven down upon the anvil R, the force of the blow being in proportion to the rate of reciprocation of the piston D. While the eccentric J is passing over its lower dead centre the piston D, with its rod and connections E, is supported by the compressed air in the bottom of the cylinder, and thus the eccentric is relieved of all thrust while reversing the motion of the rod and piston; and the same relief is accomplished while the eccentric is passing its upper dead centre by the action of the compressed air in the upper part of the cylinder. This arrangement possesses, however, the disadvantage of causing an upward thrust upon the bearings *b*, consequent upon the continued upward movement of the hammer, after the reversing of the rod E; and it is for the purpose of counteracting this strain that the intermediate cylinder L is employed. The motion of the piston P is contrary to that of the piston D, and consequently when the cylinder C descends, the piston P is drawn to the top of L, and the tension of the compressed air therein is opposed to the downward motion C; and by the proper balancing of these opposing forces all upward thrust of the journals *b* is prevented, the hammer beam B working smoothly without any jar or shock. The regulating of these forces is accomplished by means of the cock *p*, by the opening or closing of which a greater or less escape of the compressed air will take place from the upper part of the cylinder L. The piston D passes its vent *k* at midway of its stroke; but the piston P cuts off its vent *q* almost immediately that it begins to move, so that the amount of compression obtained in the cylinder L will be about double that in the cylinder C; this allows of a corresponding adjustment of the valve *p*. It is a matter of great importance in hammers of this class to be able to vary the power of the blow without altering the speed, and this is effected in this hammer by means of the valve *r*, which is placed at the bottom of the cylinder L. When *r* is closed, the air which is compressed under the piston P absorbs the force exerted by the downward stroke of the hammer, without in any way affecting its speed.

Alfred Davy's power hammer is shown in Figs. 43 to 45; Fig. 43 is a front elevation, Fig. 44 a side elevation, and Fig. 45 an enlarged

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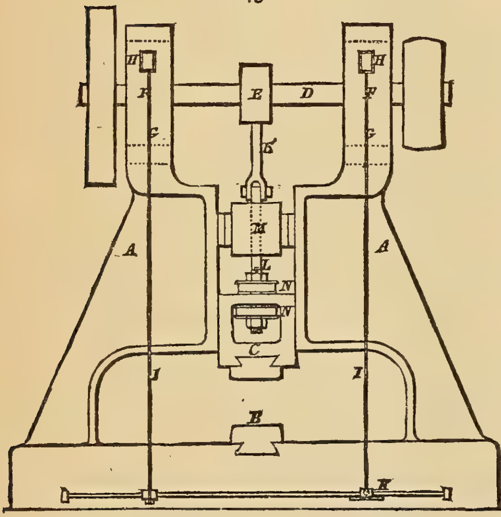

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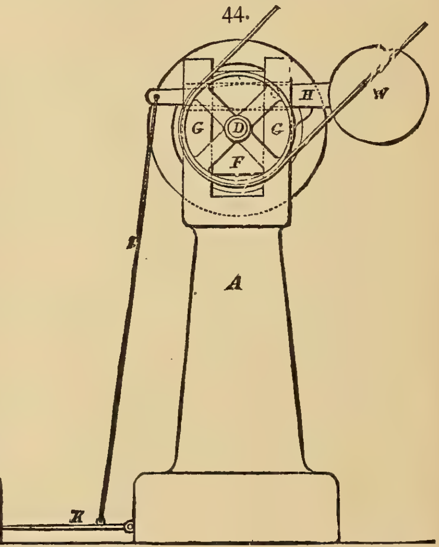

view of the tup and its connections. The shaft D is so arranged as to be capable of being raised bodily, so as to increase the distance between the face of the tup C and of the anvil B; by which means the hammer may be caused to give any number of light or heavy blows without interfering with its speed, or it may be so far raised as to be free to oscillate without giving any blow. At the upper part of the standards A are two guides G, between which are placed the bearing blocks F, which carry the shaft D; the blocks F being free to slide up and down between the guides G. To the rear guides are pivoted the levers H, which pass through slots in G. At the back of these levers are fixed weights W sufficiently heavy to counterbalance and lift the hammer tup C and shaft D with their connections, and at their forward ends the levers are connected by means of the rods I to the treadle K. The parts H which pass through the guides G are slightly rounded on their lower and upper edges. When the hammer is out of gear, the levers H cause the blocks F to rise in the guides by the action of the counterweights W; and thus lift the driving shaft D, and with it the tup C, so that the latter will continue to oscillate without striking the face of the anvil. By pressing down the treadle K, C will strike the object placed beneath it, the force of the blow being in proportion to the extent that the treadle K is depressed; the farther the latter is pressed down the heavier being the blow delivered by the tup, and conversely. The tup C, made of cast steel, has an opening *c* extending from front to back. Through the upper part passes the spindle L, on which are fixed the two rubber cushions N N′, supported in their proper position by metal discs and nuts screwing on the spindle L; the distance apart of the cushions being so regulated as to give that amount of play between them and the part of the tup which they embrace, which is best suited to the size of the work being operated upon. The spindle L passes through the guide M, bolted to the standard A, and is connected to the eccentric rod E′. The cushions prevent or minimise the shock to the driving shaft and other working parts of the hammer, and the play between them and the tup serves to accommodate the hammer to work varying in size within certain limits; sufficient play being always allowed to permit of the tup falling entirely independent of its connections, so that the force of the blow is due solely to the velocity and weight of the tup, and is not either accelerated or

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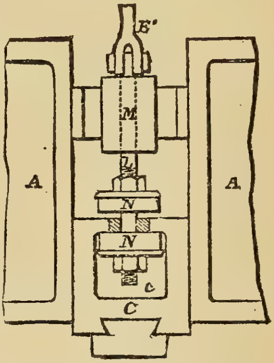

retarded, by the indiarubber cushions, at the instant the work is struck.

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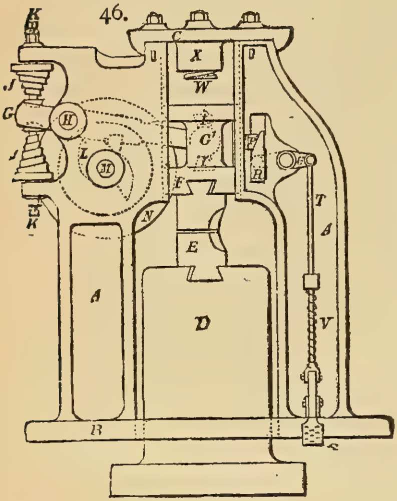

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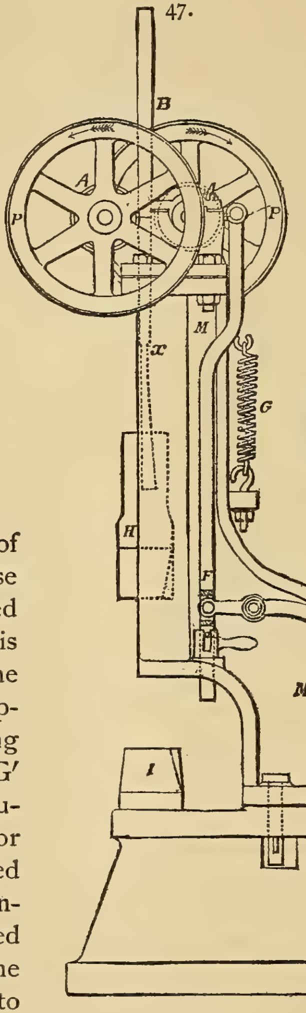

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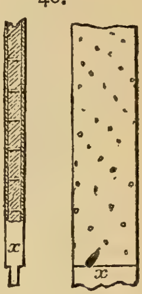

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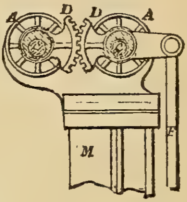

Fig. 46 is a front elevation of Glossop's hammer. The power is applied to a pulley on the shaft of the flywheel N by a belt, the hammer being lifted by means of the cams L which are fixed to the shaft M. The frame A is of cast iron, secured to the base plate B, and is further secured by means of the cap C. D is the anvil block supporting the anvil E. The tup F is supported by the lever G, having its fulcrum at H. The end G′ of this lever is made of a circular form; the opposite or shorter end of the lever is acted upon by the springs J, the tension of which can be regulated by means of the screws K; the object of these springs being to balance the weight of the tup F, and so reduce the work of the cams to a minimum. The rounded end G′ of the lever G bears on two removable blocks I, which are let into recesses in the tup F, so that the lifting action of the lever is always in a line perpendicular to the axis of the tup. On the sides of the tup are guide strips O, which work in grooves formed in the standards A; P and P′ are two friction blocks, having a spring between them, and R is a wedge-shaped slide which its raised and lowered by means of the treadle S acting through the rod T and lever U, the wedge R being forced upwards and held at is highest position by the action of the spring V on the rod T; and when the wedge is in this position, the lever G is supported out of reach of the cams L, so that the shaft M may continue to revolve without causing the hammer to act. On the under side of the cap C is a box X, in which is secured a strong rubber or steel spring W. When the hammer is in gear, the tup is propelled against this spring by the action of the cams L on the lever G, causing the tup to descend with a much greater force than it otherwise would. The motive power having been applied to the pulley on the shaft M the latter will revolve, and with it the cams L; the workman then presses down the treadle S which releases the tup, the revolution of the cam L then lifts the lever G, and with it the tup F, and when the point of the cam passes the projection on the lever G the tup drops; the speed, however, at which the lever is lifted by the cam propels it considerably higher than the cam itself, and causes the tup to strike against and compress the spring W, the reaction of which accelerates the fall of the tup, and increases the power of the blow. In order to obtain a lighter blow the pressure of the operator's foot on the treadle S is partially withdrawn, and the action of the spring V on the friction blocks causes a pressure on the long strip O, thus retarding the action of the tup; and when the pressure of the foot is entirely withdrawn from the treadle, the tup will be caught at its highest point, and held by the friction blocks suspended out of reach of the action of the cam I until pressure on the treadle again releases it.

Hasse's friction forge hammer, shown in side elevation in Fig. 47, differs considerably in its mode of action from those already described, resembling somewhat that of a pile driver. At the top of the main framing M are two friction rollers A, the axes of which revolve in eccentric bearings C, to which are connected the segmental racks D gearing into each other. By raising or lowering the rod F, by means of the lever arm E, the axes C are brought nearer to or more distant from each other; the arm E being so balanced by the action of the spring G, which is attached to the rod

F and to a part of the main framing M, that this lever E will remain suspended in the position in which it may be at the moment when released by the workman. In order to ensure, as much as possible, the uniform rotation of the friction rollers A, each of the axes C is provided with a fly-wheel P, either of which may be used as a driving pulley. The hammer block H is attached to the hammer stem B, Figs. 47 and 48; it consists of a strong central core with a facing on each side, the whole securely bolted together and firmly held by trenails; the grain of the facing should run in a diagonal direction, and it is best for the two sides of the stem to have the grain running at right angles to each other; the object of this arrangement is to expose a better biting surface to the rollers A than would be the case if the grain ran in the usual perpendicular direction. The hammer stem is made with a gradual taper on each side, and is formed with a sudden reduction of thickness at x. Motion being imparted to the friction rollers A, Fig. 49, by means of a belt applied to one of the flywheels, the workman raises the lever E until the friction rollers nip the hammer stem, and the latter is then lifted by virtue of the friction which is produced between it and the rollers; by pressing down the lever E the hammer stem is released, and the hammer falls on to the anvil I, the force of the blow being in proportion to the height to which the hammer has been lifted. As the hammer stem is of a tapering form, it will only be raised by the friction rollers so long as they continue to approach each other, and so follow the reducing thickness of the stem; and consequently the hammer will only continue to be lifted as the operator continues to raise the lever E; when this is released the hammer will be held suspended by the action of the spring G. After the hammer has been raised to its full height the sudden thinning of the stem at x prevents it being raised any farther, and so avoids injury to the friction rollers. By these arrangements the hammer is capable of delivering blows with any required degree of rapidity or force; while at the same time it will be found almost as easy to control as an ordinary steam hammer.

Stacy's revolving hammer, Fig. 50, is arranged to deliver a series of elastic blows in very rapid succession. When employed for shaping round bars, the faces of the hammers G and of the anvil I are shaped as in Fig. 51; for reducing the thickness of plates, a hammer face as in Fig. 52 is employed, where the rounded part of the face gives the blow, the flattened portion of the same acting as stops to regulate the amount of reduction in thickness which shall be given to the plate. The rotary shaft A is mounted in the arms B; the opposite ends of these arms being carried by the fixed axle C which is supported by the brackets D. Through the front end of

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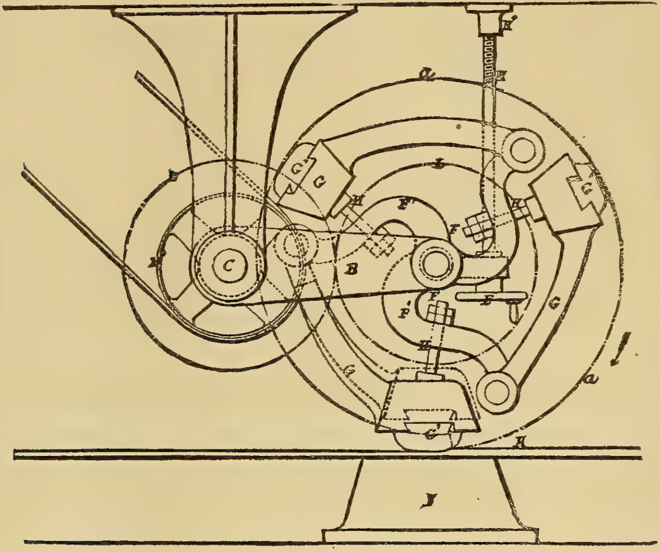

the arm B there passes a rod E, the upper part of which is provided with a screw thread working in a fixed nut E'; and by means of this rod the axis A may be raised or lowered at pleasure, so as to accommodate the hammers G to the thickness of the work, and to regulate the force of the blow to be given. The curved arms F' are cast with the boss F, and to their ends the hammers G are hinged; the joint pins of the hammers being equidistant from each other and from the axis of rotation. The arms F', at about the centre of their length, are cast with swells having holes pierced through them to allow of the passage of the stop-pins H, which are screwed into the backs of the hammer heads G, and they are fitted with adjusting nuts at their free ends for determining the distance which the hammers shall fly out when

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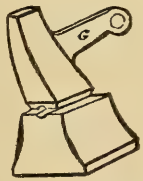

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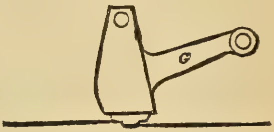

impelled by centrifugal force. The hammer faces are slightly rounded at their forward part for the purpose of allowing the hammer to come fairly over its work before striking, and so causing it to deliver a swinging blow in the direction of a line radiating from the central axis of the machine. The shaft A is driven by spur wheels L L′, and these receive motion from a belt and pulley M M′. The spur wheel L is keyed to the shaft A, and the wheel L′ and pulley M′ are keyed to a sleeve on the shaft C. When the shaft A is slowly rotated in the direction of the arrow the hammers are drawn over the work, simply pressing with the force due to their weight, controlled however by the stop-pins H; but as soon as the proper speed is attained, this dragging pressure is converted into a smart blow, the recoil from which will carry the hammer clear of the work. As the stops H revolve with the hammers, they limit the movement of the latter outwards, or away from the axis of rotation during their entire revolution; the blow is delivered while the hammer is at its outermost limit *a* against the stop. This hammer may be constructed with a greater number of striking faces G′, but in this case the hammers G are carried by two circular flanged plates N, Fig. 53, and in place of the stops H, a series of radial slots *h* are provided equal to the number of the hammers, and in these

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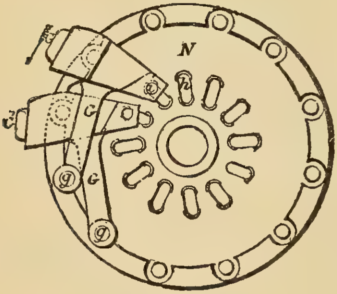

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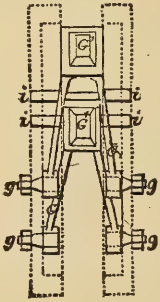
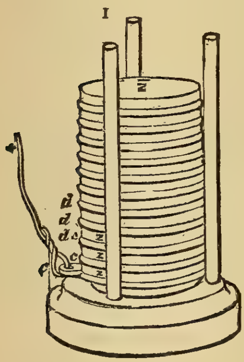
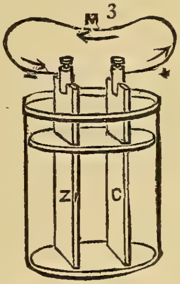


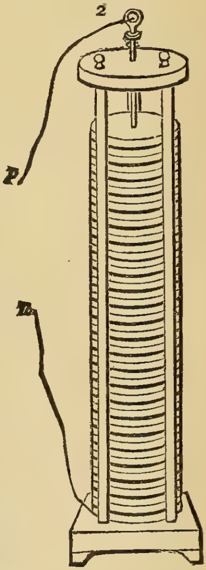
slots slide the stop-pins *i*, the ends of the slots *h* being packed with some elastic substance in order to reduce shock. The hammers G are connected to the discs N by means of stud pins which pass through socket holes in them. The stems of the hammers G are forked to allow the head of the adjacent hammer to pass through, as in Fig. 54, and for the same purpose the sides of the hammer heads are recessed in order to allow of the free play of the hammers each within and independent of the other. Instead of employing the method of mounting and gearing, Fig. 50, the hammer may be supported in bearings in the hanging brackets D, and driven direct from the belt by means of fast and loose pulleys on the shaft A; but in this case the anvil I must be capable of being raised and lowered to suit the different thicknesses of the work operated upon, and also for the purpose of regulating the force of the blow.

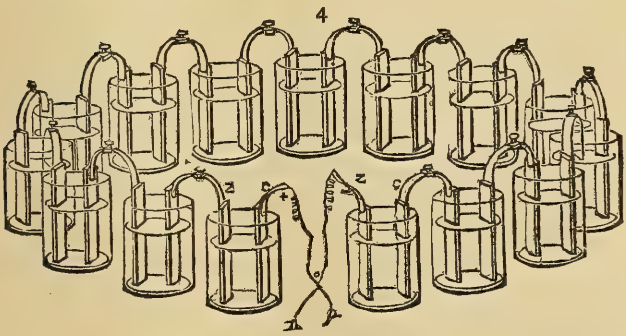
ELECTRIC ENGINEERING.

A SERIES of voltaic elements, cells, couples, or pairs, arranged in such a manner that the zinc of one element is in connection with the copper of another element; the zinc of this with the copper of a third, and so on; such an arrangement is termed a Galvanic or Voltaic Battery.









The earliest galvanic battery was constructed by Volta in 1800. It consisted of an insulated plate, Fig. 1, upon which was placed a series of discs of copper and of zinc soldered together. Above the copper of the first disc was placed a disc of cloth *d*, saturated with acidulated water; upon the disc of cloth was then laid another metallic disc. These discs were thus alternately laid one upon another, until a pile, Fig. 2, had been built up, care being taken to lay them the same way. To the ends of this pile were attached wires *p* and *n*, which, when connected in any way, set in motion a current of electricity.

The piles constructed in this way were, however, but weak, and useless for experiments which lasted any length of time; for as the number of elements was augmented, the weight of the upper discs pressed the liquid from the lower discs, which became dry, and so lost their conductibility. This led Volta to invent the improved modification shown in Fig. 4, which he called the *couronne de tasses*, or crown of cups. Instead of the damp cloth of the pile, a number of jars, arranged in a circle, and filled with acidulated water, are employed. The jars communicate successively one with the other by means of metallic arches formed of a plate of zinc soldered to a plate of copper; the copper of each arch being plunged into the jar which precedes it, and the zinc into the jar which follows it. The two jars which form the extremities of the series receive respectively a plate of zinc Z, and a plate of copper C, to each of which is fastened a conducting-wire. The first corresponds to the negative pole and the second to the positive pole.

To comprehend the principle of this battery, we will suppose that two plates, cut, one Z from a sheet of zinc, and the other C from a sheet of copper, Fig. 3, are placed, without contact with each other, in a jar containing slightly acidulated water. To the upper edges of the plates let two pieces of wire be fastened. In this state the apparatus will manifest no development of the electric fluid; but if the ends of the wires be brought into contact at M, an electric current will be set in motion, passing through the wires from the point where the wire is fastened to the copper C, to the point where the other wire is soldered to the zinc Z. The current will continue to flow so long as the ends of the wires are in contact, but the moment the ends are separated the current ceases.

It will be seen that the electric fluid is evolved by the combination of three bodies—the zinc, the copper, and the acidulated solution in which they were immersed. The production of the current depends on the chemical action of the solution on the zinc. That metal being very susceptible of oxidation, decomposes the water which is in contact with it. One constituent of the water combining with the zinc produces a compound called the oxide of zinc, and this oxide entering again into combination with the acid which the water holds in solution, forms a soluble salt. If the acid, for example, be sulphuric acid, this salt will be the sulphate of the oxide of zinc; and as fast as it is produced it will be dissolved in the water in which the plates were immersed. The copper not being as susceptible of chemical action as the zinc, remains comparatively unaffected by the solution; but the hydrogen evolved in the decomposition of the water collects upon its surface, after which it rises and escapes in bubbles at the surface of the solution.

It is to this chemical action upon the zinc that the production of the electric current is due. If a similar action had taken place in the same degree on the copper, a similar and equally intense electric current would be produced in the opposite direction; in that case the two currents would neutralize each other, and no electric effect would ensue. From this it will be seen that the efficacy of the combination must be ascribed to the fact that one of the two metals immersed in the solution is more oxidizable than the other, and that the energy of the effect and the intensity of the current will be so much the greater as the susceptibility of oxidation of one metal exceeds that of the other.

It appears, therefore, that the principle may be generalized, and that electricity will be developed and a current produced by any two metals similarly placed, which are oxidizable in different degrees. And, indeed, if two pieces of the same metal are differently acted upon, either by heat or chemically, a current of electricity will be produced on their being connected together.

Zinc being one of the most oxidizable metals, and being also sufficiently cheap and plentiful, is generally used for voltaic combinations. Silver, gold, and platinum are severally less susceptible of oxidation, and of chemical action generally, than copper, and would therefore answer voltaic purposes better, but are excluded by their greater cost, and by the fact that copper is found sufficient for all practical purposes. It is not, however, absolutely necessary that the inoxidizable plate C of the combination should be a metal. It is only necessary that it be a good conductor of electricity.

In certain voltaic combinations, charcoal properly solidified has therefore been substituted for copper, the solution being such as would produce a strong chemical action on copper. Each combination of two metals or of one metal and charcoal, is called either a cell, a couple, an element, or a pair.

A series of jars, Fig. 5, when arranged in a similar manner to Volta's *couronne de tasses*, that is, the zinc of one jar in connection with the copper of the next jar, the order being zinc, acid, copper, zinc, acid, copper, and so on, is termed a battery, and by its means the effects produced by a single element are capable of being greatly increased. If, however, only one element is employed, it is in itself a battery.

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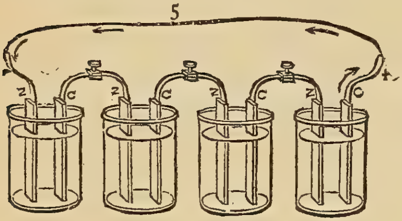

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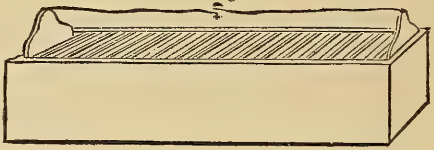

The part of a battery from which the current is supposed to proceed is called the positive pole, and the part towards which the current flows, the negative pole. These poles, shown at + and –, Fig. 5, are often termed electrodes, so that + would be the positive and – the negative electrode.

The arrangement of the *couronne de tasses*, and of batteries similarly constructed, was so cumbersome that they were soon superseded by the Trough battery, which is shown in Fig. 6. This battery was invented by Cruickshank, and consists of a rectangular water-tight trough divided into cells by plates formed of zinc and copper soldered together. The cells are filled with acidulated water or a solution of salt and water; and two plates of copper, furnished with conducting wires, are immersed in the last cell at each end. It was with a battery of this kind, composed of 3,000 couples, that at the commencement of the present century Davy succeeded in decomposing potash and soda, and thus discovered potassium and sodium. The trough battery is rather inconvenient on account of its weight, and also through the wood of the case warping under the action of the acids.

The arrangement introduced by Wollaston is more convenient.

An element of Wollaston's battery, Fig. 7, is composed of a plate of zinc Z, round which is bent a plate of copper C, actual contact being prevented by placing small pieces of wood or cork between the plates. When the element is to be put in operation, it is immersed in a vase containing acidulated water; the negative pole then establishes itself at the wire connected with the zinc, and the positive pole at the wire fastened to the copper. To unite several elements into a battery, it is necessary to connect the copper of each element with the zinc of the following. The elements thus connected can then be mounted on a stand, Fig. 8, and, when the battery is to be operated, plunged separately into vases containing the exciting liquid. The necessity of a vase for each of the elements of Wollaston's battery renders it cumbersome.

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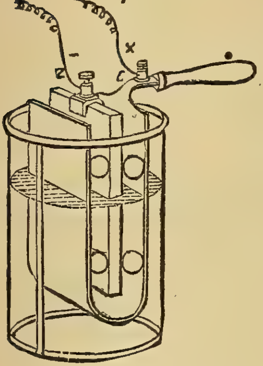

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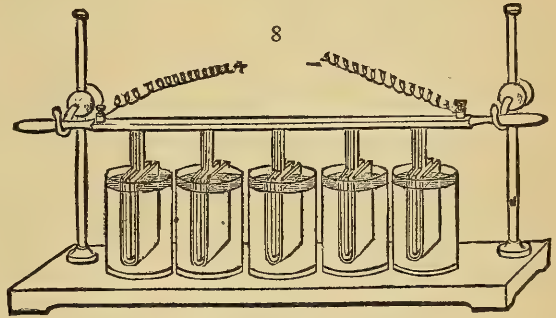

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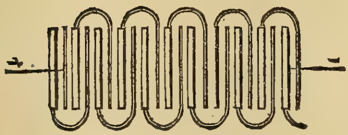

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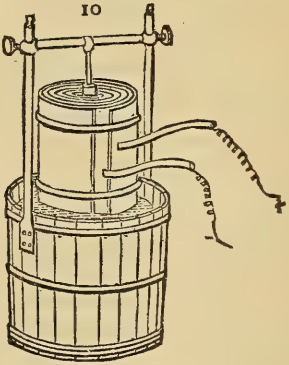


Muncke's battery removes this inconvenience, as by its means we can have a considerable number of elements in a small space. The plates of zinc and of copper are soldered together vertically, bent to the form of the letter **U**, and then fitted alternately one into the other, Fig. 9, in such a manner that the alternation of the metals is complete. Together the elements form a single system, which is fixed in a wooden frame, and, when required for use, immersed in a stone trough filled with acidulated water.

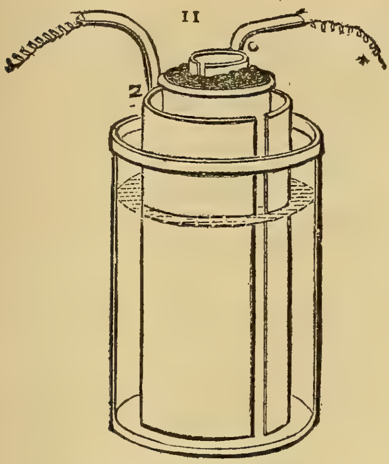
Batteries composed of a number of elements, as Muncke's battery, are especially applicable when the current encounters in its polar circuit any great resistance. When this resistance is weak, it is preferable to have the advantage of increasing the area of the surface of the elements rather than their number. This condition is realized by Dr. Hare's cylindrical battery, Fig. 10, which consists of a large sheet of zinc and one of copper, soldered together at one end. The sheets are rolled, without touching each other, round a cylinder of wood, and each is attached to metallic conducting-wires; the negative wire is that in connection with the zinc, and the positive wire that fastened to the copper.

When the apparatus is to be used, it is plunged into a tub containing acidulated water. When several of these elements are united in a battery, an apparatus is obtained, of which the caloric power is so great as to have obtained for it the name of a calorimotor.

The batteries we have described present practically several serious inconveniences. The water being decomposed by the zinc, liberates hydrogen, which, charged with acid particles, is released into the air, rendering in a very short time the surrounding atmosphere irrespirable. Besides this, the liberated hydrogen adheres as a film on the surface of the copper, presenting a great resistance to the current, and sensibly diminishing its intensity. Lastly, this film has a variable thickness, from which results a perpetual variation in the intensity of the current itself. These inconveniences, however, disappear in a greater or less degree in batteries operated by two liquids.

Daniell's Battery.—An element of Daniell's battery, Fig. 11, consists of an outer jar containing acidulated water in which is immersed a cylinder of zinc Z, in the interior of which is placed a porous earthenware pot, filled with a solution of sulphate of copper which surrounds a cylinder of copper C. The conducting-wire attached to the zinc, Fig. 11, corresponds to the negative pole of the element.

It is easily seen that in this arrangement the film of hydrogen which acts so disadvantageously in ordinary batteries, no longer exists; and the metal, following the same direction as positive electricity, deposits itself upon the copper cylinder. The disengagement of the hydrogen is replaced by a decomposition of the copper, which does not change the physical condition of the system. The action of this battery is very regular, it lasts a long time without renewal and the surrounding atmosphere is not sensibly affected by its fumes.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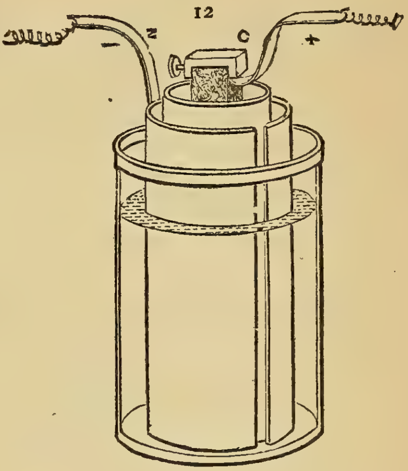
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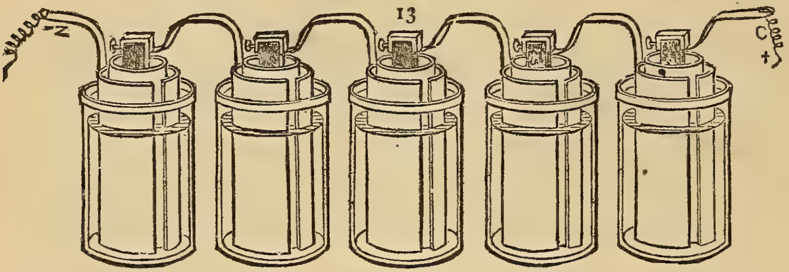
Amongst the causes which vary the intensity of the current in this battery is the change in the nature of the liquids, the acidulated water becoming charged more and more with sulphate of zinc; and the decomposition of the sulphate of copper. Experience has shown that the first circumstance does not affect the intensity of the current in any sensible degree. To remedy the second, in proportion as the sulphate of copper is decomposed, fresh portions of that salt are added; and for this purpose there is a sort of perforated flange on the upper part of the copper cylinder, which is kept filled with crystals of sulphate of copper.

Bunsen's Battery consists of a vase, Fig. 12, containing dilute sulphuric acid, in which is placed a plate of zinc Z as in Daniell's battery; but in the porous pot is poured nitric acid at 40°, and, instead of the copper, a prism of charcoal, made from the residuum taken from the retorts of gas-works, is used.

To form a battery, Fig. 13, the carbon of one element is united with the zinc of the following element, by means of clamps, the positive pole evidently corresponding to the last carbon, and the negative pole to the last zinc.

In Bunsen's battery, the hydrogen liberated by the decomposition of the water decomposes in its turn the nitric acid in which the carbon is immersed; the result is that hyponitric acid is formed, which gradually dissolves, and never shows itself in the form of bubbles.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Bunsen's battery is only a modification of a battery previously invented by Grove, in which the place of the carbon was occupied by a plate of platinum; but the high price of this metal caused the use of Grove's battery to be very limited. Several inventors had thought of replacing the platinum plate by charcoal; and a few batteries of this description were in use at the time Bunsen's arrangement was introduced.

It should be noticed that a great inconvenience attends all batteries in which nitric acid is employed, owing to the diffusion of nitrous vapor which vitiates the surrounding air.

When a battery is in action, the work produced at the poles corresponds to the oxidation or consumption of the zinc, in a similar manner to the caloric engine, where the work performed is in proportion to the amount of coal consumed. If ordinary zinc is used, in batteries furnished with acidulated water, the zinc is always found attacked, whether the battery is in operation or not; but this does not occur if chemically pure zinc is used. However, there is no occasion to use pure zinc if amalgamated zinc, which is easily made, is employed.

The amalgamation of the zinc is best effected by dipping it in dilute sulphuric acid, and then rubbing it over with mercury, or by immersing it in a solution of a salt of mercury, and afterwards rubbing it briskly, when the amalgamation will be complete.

There have been numerous batteries contrived, which we do not notice, as their description would be of no interest. We only mention the Bichromate of Potash battery, which is frequently made use of in the current for the purpose of exciting various electrical machines. The element consists of a spherical-shaped bottle, with a broad neck, containing a solution of $\frac{1}{20}$ bichromate of potash, added to an equal quantity of sulphuric acid. Into the liquid is plunged a double plate of zinc, Fig. 14, in the interior of which is arranged a plate of charcoal, which answers to the positive pole. When it is desired to suspend the action of the battery, the plate of zinc is raised, so as to prevent its contact with the liquid.

The work produced by chemical action is not the only means of obtaining a galvano-electric current; the same result may be arrived at by the action of heat. This development of electricity by heat was discovered by Seebeck, of Berlin, in 1821, and is called *thermo-electricity*.

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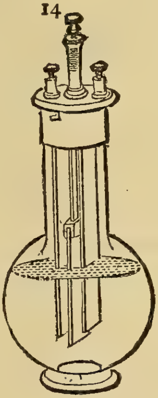

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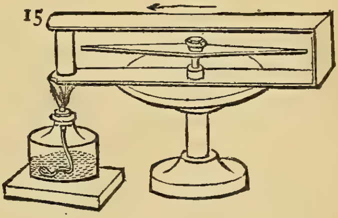

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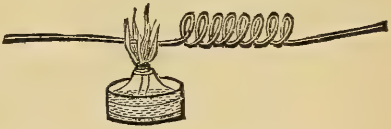

To make a thermo-electric couple, a plate of copper, Fig. 15, is bent round and soldered at its two ends to a cylinder of bismuth; we have thus a sort of rectangular figure, three sides of which are made by the plate of copper, and the fourth by the bismuth cylinder. The apparatus must be arranged in such a manner that the long sides of the rectangle are nearly in the magnetic meridian; and in the interior of the apparatus is placed a magnetic needle. If one of the compound corners of the circuit, where the two metals are joined, is heated with a spirit-lamp, Fig. 15, the needle is deflected; this denotes the production of an electric current which is directed in the copper plate from the warm corner to the cold corner. If, instead of heating the corner, it had been refrigerated with ice, it would also have produced a current, but in an opposite direction.

Although this experiment is especially sensible with bismuth and antimony, it will succeed with any of the metals. It is also not absolutely necessary to heat the point in the circuit where the two metals join, since if an elevation of temperature takes place, at any point where a perfect similarity of structure does not exist, a current immediately manifests itself. This important fact is demonstrated by various experiments. Take, for example, a piece of platinum wire which has been twisted into a knot, and heat it near the twist; it will produce a current of electricity, the force of which may be observed by placing the extremities of the wires in connection with a galvanometer. The current, it will be seen, changes from one side to the other of the knot as either side is heated.

The same result will occur if a portion of the wire is coiled into a spiral, Fig. 16, and treated in the same manner.

In metals which are similar to bismuth, not homogeneous, it is very common to observe thermo-electric currents.

It should be noticed that to a difference in structure, and to no other circumstance, as, for example, a change of dimensions, is this phenomenon attributed. When the molecular construction is the same on both sides of the heated point, there will be no current manifested. The two following experiments made by M. Magnus are decisive on this head. He reduced a copper cylinder in the middle until it was only the thickness of a fine wire; on heating the metal at the place where the sudden change in its diameter occurred, he did not observe any current, although there must have been a difference in the diffusion of the electricity from one side to the other of this point.

For his second experiment, Magnus took two tubes, A B and C D, Fig. 17, and filled them with mercury: the extremities A and D being connected with the wires of a galvanometer. The mercury contained in C was heated, and the extremity of the tube B plunged into it. In this case also no current was observed. Yet if a difference of structure is necessary to produce a current, this difference may be very insignificant. So that if the extremities of the two platinum wires were bent into hooks, and one of them after being

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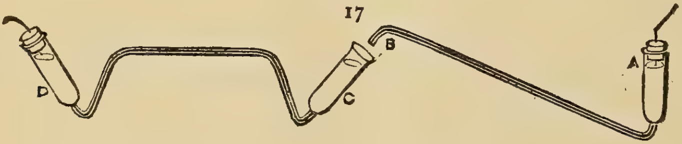

heated laid upon the other, no effect would be produced, because the action of heat upon the platinum could not make it undergo any modification. But if the experiment is repeated with copper wires, a current will occur, the action of heat having quickly produced a film of oxide which has modified the constitution of the metal.

It follows from this that the action of heat has the effect of exciting in various bodies, and particularly in metals, the movement of fluids which characterize the electric current. If in a homogeneous conductor no effect is observed, it is because the two currents produced on each side of the heated point are equal and in contrary directions; but a difference of structure modifies the intensity of one of the currents, and the galvanometer shows the resultant produced from the two effects.

When the soldered joint of two different metals is operated upon, the direction of the current depends upon the nature of the metals associated, and it is impossible to give any precise rule upon this point. In the following list, the result of experiments made by Becquerel, the current traverses the heated joint, proceeding in consecutive order through the metals:—bismuth, platinum, lead, tin, copper, silver, zinc, iron, antimony.

The *intensity* of thermo-electric currents also depends upon the nature of the metals joined together; and each of these associations has an electromotive force peculiar to itself, which has been called *thermo-electric power.*

For the purpose of comparing these thermo-electric powers, Becquerel made use of a chain, A, B, C, D, E, F, G, Fig. 18, formed of several metals soldered successively one upon the end of the other. The ends of the chain being attached to a galvanometer, one of the joints was heated at a fixed temperature, 40° for instance, whilst the other joints were kept at zero.

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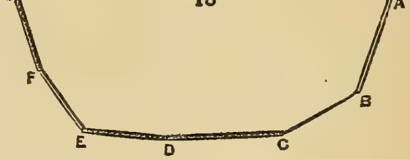


The current produced having in each case to traverse a circle of equal resistance, its intensity may be considered as the proportional measure of the thermo-electric power of the joint, at least, from the temperature from which we operate.

It was in this manner that Becquerel obtained the following Table:—

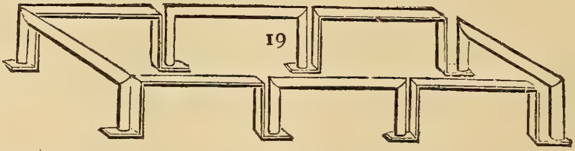
Iron—Platinum	36·07
Iron—Tin	31·24
Iron—Copper	27·96
Iron—Silver	26·20
Copper—Platinum	8·55
Copper—Tin	3·50
Copper—Silver	2·00
Zinc—Copper	1·00

In these experiments Becquerel has proved the following fact, which is of real importance.

Supposing a joint of iron and copper to be heated, we shall have a current of a certain intensity; if between the iron and copper a piece of metal is interposed, or a chain of several metals of which we heat the two end joints, we shall have exactly the same results. This is a proof that the current is really due to the difference in the propagation of heat in the metals, and not, for instance, to contact.

The intensity of the current produced by a thermo-electric couple depends on the difference of temperature of two combined joints; and, within certain limits which are variable, as well as according to the metals employed, it is sensibly proportional; but after a certain time the increase in the intensity of the current abates very considerably. Thus for a couple of iron and copper it is scarcely sensible at 300°; beyond this the intensity of the current diminishes, becomes null, and ends by changing its direction. It should be noticed that the difference of temperature is not the *only* influence on this phenomenon—the absolute temperature must also be taken into account. Thus the current has not the same intensity, one of the joints being zero and the other 20°, as if the temperatures had been at 100° and 120°.

By joining together a number of thermo-electric couples and heating simultaneously the equal joints, we obtain a Thermo-electric battery. Fig. 19 represents an apparatus of this kind invented by Pouillet. It is composed of cylinders of bismuth bent at their extremities, and connected one with the other by means of plates of copper, also bent and soldered to the bismuth. If we plunge every second joint into any cold body—melting ice, for instance—whilst the remaining joints are heated at a fixed temperature, the battery produces a current which can be collected on a conducting-wire as in an ordinary battery.



Viewed as agents for the production of the electric current, thermo-electric batteries have not as yet given very useful results as thermo-electric currents weaken rapidly, in circuits where there is little resistance, through the conductibility of the mediums in which they are generated. Thus 120 couples at least of iron and platinum are necessary to produce an appreciable decomposition of water.

Edmond Becquerel has recently introduced, however, a thermo-electric couple of exceptional power; it is formed by connecting a plate of German silver N, Fig. 20, and artificial sulphate of copper M, the positive pole corresponding to the sulphate of copper.

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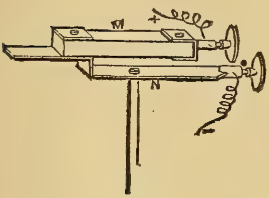

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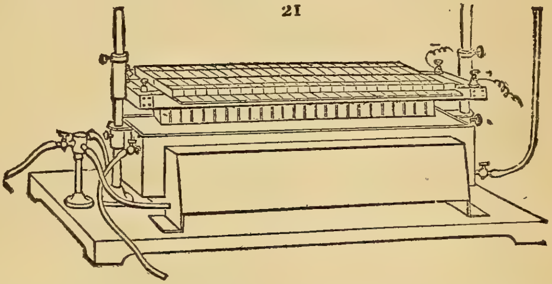

Fig. 21 shows a battery constructed upon this plan. The temperature of the joints is raised by means of common gas; and with thirty or forty elements it is capable of sensibly decomposing water, of maintaining an electro-magnet with a long coil, and of working a telegraphic apparatus.

Until lately, thermo-electric currents have only been made use of to measure temperatures under special conditions. The thermo-electric tongs invented by Peltier, are, however, useful for indicating the temperature of any limited space. They consist of two thermo-electric couples, Fig. 22, of bismuth and of antimony, *a b* and *a′ b′*; the bismuth of one element being united by a wire to the antimony of the other, and the circle completed by a galvanometer. It results from this arrangement that if the space comprised between the two joints *c* and *c′* becomes at all warm, a current from the bismuth to the antimony will be produced in the two couples. These two currents act, besides, upon the magnet in the same direction; and as

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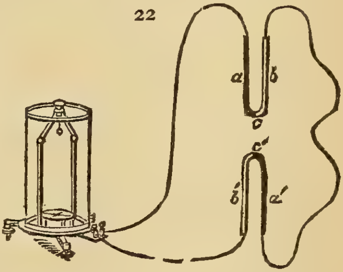

the bulk of the instrument is small, and its calorific capacity feeble, its sensibility is very great.

It is with a species of very fine thermo-electric plummet that physicists are able, in certain cases, to penetrate without injury those organs which they wish to have access to in order to study the temperature of organized beings, as to the variations experienced under particular circumstances.

Byrne's Compound-plate Battery, specially known as the pneumatic battery, is chiefly distinguished by the negative plate, which, instead of being one material, is formed of three metals soldered together. The surface exposed to the exciting solution and opposed to the positive or zinc plate, is platinum, P, Fig. 23, backed by and soldered to a plate of sheet lead L. Behind this lead is a plate of copper C′ backed by another sheet of lead or fold of the first lead plate doubled on to the back of the copper. The outside or back surface of this second layer of lead is coated with asphaltum varnish *a*. Fig. 23 is a vertical cross section of the compound negative plate in which the thickness of its laminæ are exaggerated in order to show its construction. The copper plate C′ is completely enveloped by the lead L, both with regard to its face and edges, so that the copper core is in no way exposed to the exciting solution of the battery.

The total thickness of the compound plate does not exceed one-eighth of an inch; the lead weighs 8 ozs. to the square foot, and the thickness of the platinum P is one two-thousandth of an inch. Each cell contains a central zinc plate Z, Fig. 24, placed between two of the compound plates described, C C, Fig. 25, the disposition of the plates being similar to that adopted in Wollaston's battery.

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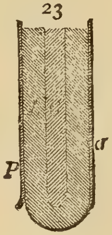

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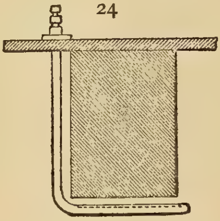

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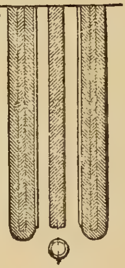

The exciting solution is similar to that used in the ordinary bichromate or Poggendorff battery, 5 ozs. of potassium bichromate dissolved in 5 pints of boiling water, to which is slowly added, when cold, 1 pint strong sulphuric acid. In the pneumatic form of the compound-plate battery, the exciting solution is kept in a state of mechanical agitation, by air being pumped into the cells through an ebonite tube, leading from each cell-cover to the bottom of the cell, where it turns at right angles, so as to lie in a horizontal position underneath and in a line with the central zinc plate, and between the compound plates. The horizontal portion of this tube is perforated by two rows of small holes, one on each side of the middle line of its upper surface, and through these holes, when the apparatus is in action, jets of air are injected into the cell, which, rising in the form of bubbles between the plates, keeps the solution in violent agitation, washing off from the plates bubbles of hydrogen which otherwise would collect, and insuring fresh fluid being continually brought into contact with the plates. The air tube, Fig. 24, terminates above the cover in a nozzle, to which is attached a vulcanized tube leading to a small hand syringe or bellows. Pumping in air has the effect of increasing the strength of the current, at the same time causes the temperature of the cell to be greatly raised, so that if the action be continued sufficiently long the solution will commence to boil.

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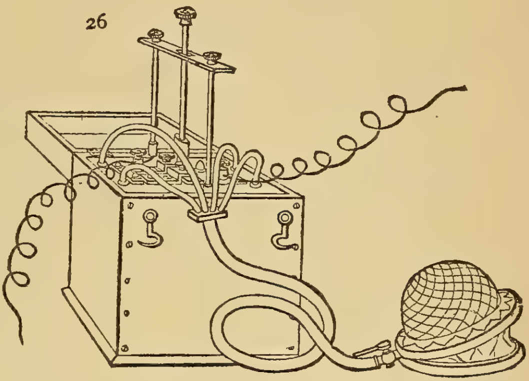

Fig. 26 is a battery of four cells covered by an ebonite plate, from which are suspended the plates, and to which are attached the exterior terminals and commutators. Rising from the edges of the box containing the battery are two vertical pillars, supporting a horizontal cross piece, through the middle of which passes a vertical rod, so that the ebonite cover-plate may be raised, and the plates lifted out of the solution. The apparatus is contained in a box measuring 7 in. by 4 in., by 6 in. deep. It is capable, when air has been pumped in, of illuminating a small electric lamp, and of heating 8 in. of platinum wire to incandescence. There is but slight heating effect upon the platinum wire before air is admitted, but as the bellows are worked, the temperature of the wire rapidly rises to a brilliant red heat, and cools when the air injection is cut off.

The cauterizing apparatus is a surgical instrument, constructed of some insulating material, and carrying at its extremity either a loop, or a straight piece of platinum in the form of wire or of a flat band, according to the requirements of the case, which, by being brought into the circuit of the battery by means of insulated conductors passing down the stem of the instrument, can be made white hot, and the cauterizing operation performed.

Larger forms of apparatus for showing more powerful effects consist of ten cells, and when air is pumped in will heat to incandescence 36 in. of stout platinum wire and decompose acidulated water at the rate of producing 16 cub. in. of gas a minute. This battery charges to its fullest extent an induction coil, giving sparks in air 18 in. in length, while air is pumped in, falling to 8 in. when the air supply is removed.

A modification of Byrne's compound-plate battery for driving machines by means of electro-magnetic engines, or for electro-plating and other chemical applications, is the Motor battery by the same inventor. In the Motor battery there are but two plates to each cell, one compound plate and one of zinc, and the exciting solution employed is sulphuric acid diluted with nine times its bulk of water. As there is no occasion for the blowing apparatus, the platinum face of the compound plate is platinized, adherent hydrogen being thus got rid of. Byrne states that eight cells of this battery are sufficient to drive a Singer sewing machine.

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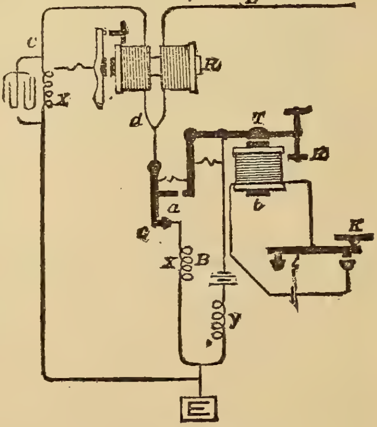

For plating purposes four cells of Byrne's Motor battery, containing plates of 20 sq. in. of surface, measuring 5 in. by 4 in., is more effective than six cells of Smee's battery, with plates having a surface of 60 sq. in.

Simultaneous Transmission.—When J. B. Stearns, of Boston, commenced his experiments in simultaneous transmission in 1868, very little was known in America respecting the previous labors of European electricians. Stearns improved on the Siemens-Halske method; that which had given the best results in practice. During 1872 improvements were added to Stearns's system which led to its immediate adoption upon many of the most important lines in the United States. The general principle of Stearns's apparatus does not differ materially from that of Frischen. In Fig. 27 the key is replaced by a transmitter T, which is controlled by a key K, a local battery and an electro-magnet *t*. The principal object in introducing this modification was to adapt the system to the use of the American operator, who is accustomed to hearing the accompaniment of his own sounder when transmitting. The transmitter acts upon exactly the same principle as Nystrom's key, the contact of the battery with the line being made before the contact between the latter and the earth is interrupted. The resistance X in the artificial line is made equal to that of the main line. When the key K is depressed, the circuit of the local battery is closed, the electro-magnet *t* attracts its armature, operating the transmitter T, which first makes contact at *a*, and almost at the same instant lifts the contact lever, which is pivoted, and breaks contact at *c*. The current from battery B now goes by way of the transmitter T, and thence through *a* and *b* to the point *d*, where it divides into two equal portions, one going through the right-hand coil of the differential relay R to the line L, and thence to the earth at the distant station, and the other by way of the left-hand coil of the relay through the rheostat X, and thence directly to the earth. As these two branches or divisions of the current are equal and opposite in their effects upon the relay R, it will not respond. The incoming currents from the distant station, on the contrary, pass only through the right-hand coil of the relay R, and thence find their way from *d* to the earth by way of *c* and *x*, or else by *a*, T, B and *y*, the route depending upon the position of the transmitter. The resistance *y* is termed the spark coil, and is only required when a battery of small internal resistance is used, in which case the spark caused by the momentary short circuiting of the battery at *a c* would otherwise cause some embarrassment. The resistance *x* is made equal to the resistance of the battery, added to that of the spark coil in case the latter is used, and thus the incoming current always meets with exactly the same resistance, irrespective of the route by which it passes from the point *d* to the earth at E.

The diagram Fig. 28, represents the arrangement at a terminal office. The continuous lines represent the main wires, and the dotted lines the local wires. K K′ are keys in a local circuit which operates the transmitter T. L L′ are local batteries. M is a main battery; G, earth; S, common Morse sounder; R *h*, rheostat; C, condenser; R, duplex relay; *t t'* are binding posts connected with the adjustable resistance coils; *r r'* are the terminals of small resistance coils, used for maintaining an equal resistance when line is to earth through battery, or to earth direct. The plugs in the resistance coils must be removed until the resistance of the coils equals the resistance of the line. When they are equal, the armature of the relay will not be affected by the working of the transmitting sounder. The object of the condenser is to receive a charge from the main battery equal to that entering the line, which charge being returned through the relay coil connected with the rheostat, at the same time that the line returns its charge through the other coil, neutralizes its effect upon the armature. The small resistance coils represented in Fig. 28, as being enclosed in the box containing rheostat *Rh*, at *r* and *r'*, are generally enclosed in separate boxes.

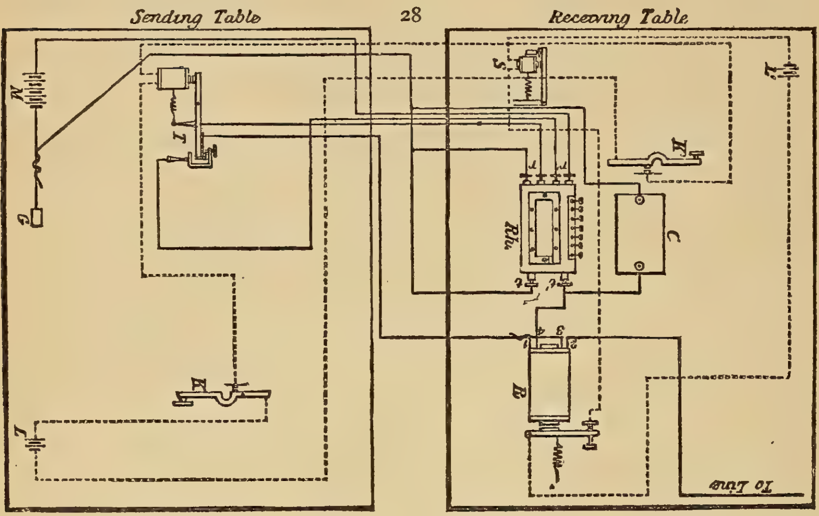

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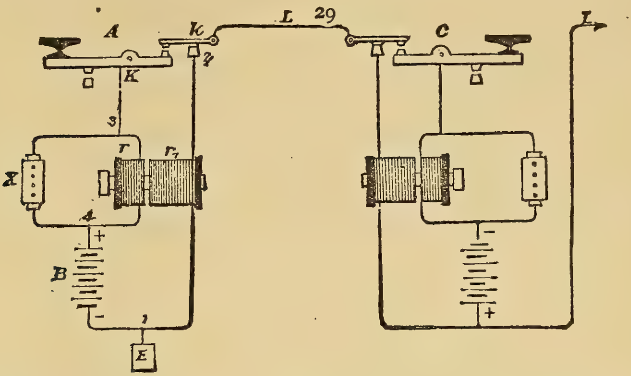
Fig. 29 is a diagram of the connections representing a terminal station A, and an intermediate station C, on M. G. Farmer's duplex system, of which there may be any required number. It is only necessary to describe the arrangement at the terminal station A. The relay is provided with two coils, r and r_1, which are so wound as to assist instead of opposing each other, as in Frischen's plan. The coil r_1 contains about twice as many convolutions of wire as the coil *r*, or it may be otherwise arranged; the object being that with a given current the coil r_1 shall exert twice the magnetic effect upon the relay that the coil *r* does. The line wire which enters the station is divided into two branches at K, one branch going directly to



the earth by way of 2 and 1, passing through the coil r_1, and the other by way of K, 3 and 4, passing through the coil *r*. For transferring the incoming current from one of these branches to the other, Farmer employed a continuity preserving key K*k* upon the same principle as that used by Nystrom in 1855. When the apparatus is in a position of rest, the route of the incoming current is by way of 2, r_1 and 1 to the earth at E. If the key K is depressed, the circuit of the main battery is closed, by the contact of its rear end with the supplementary contact lever *k*, which is at the same time lifted from the point 2. The outgoing current now passes through the coil *r* of the relay at the home station, and through the coil r_1 at the distant station. As the coil r_1 produces quite as great a magnetic effect upon the relay R as the coil *r*, it is easy to so adjust the respective relays that the distant one shall attract its armature, while that at the home station remains unaffected. When both keys are depressed, the circuit is through the coil *r* at each station, but the effect upon each relay is doubled, because the line is traversed by the combined current of two batteries. In order to render it certain that the receiving instrument at the home station should remain unaffected by the outgoing current, Farmer made use of the device employed by Gintl in 1855; an adjustable rheostat X placed in a branch circuit or shunt passing around the receiving instrument, by which means so much of the outgoing current can be made to pass through the shunt, that the remaining portion will not be sufficient to produce any effect upon the receiving instrument.

The method of inserting any required number of intermediate stations, devised by Farmer in connection with this invention, is represented at C, in Fig. 29. The only variation from the ordinary arrangement of a terminal station consists in connecting the line wire running in one direction in the place of the earth wire. When the key is depressed at the intermediate station, the relays of both terminal stations respond, as the battery current traverses the entire line. This arrangement is of course applicable to any other similar method.

The diagram, Fig. 30, illustrates the principle of another method

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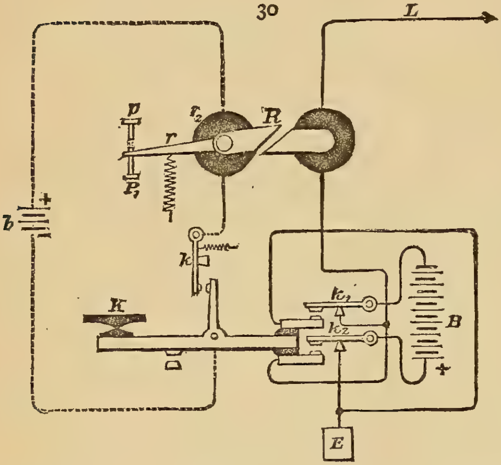

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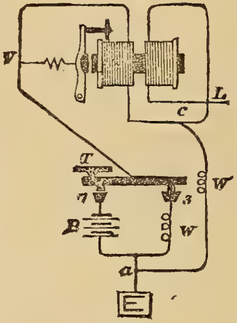

by Farmer. The key K, when depressed simultaneously, lifts three separate contact levers, *k*, k_1, k_2. The contact levers k_1 and k_2 are so connected with the main battery B, line wire L, and earth E, that the depression of the key has the effect of interchanging the poles of the main battery, with respect to the line and earth wires, or in other words, of reversing the current upon the line. This reversal is effected without at any time interrupting the continuity of the main circuit. The relay R is constructed with two separate coils, r_1 and r_2, the former being included in the main circuit, between the key and the earth, and the latter in the circuit of a local or equating battery *b*, by the contact lever *k*, whenever the key is depressed, at the same instant that the battery is reversed upon the main line. The cores of the two coils of the relay are provided with bevelled pole pieces, which are so arranged that they act as armatures to each other. The core of r_1 is fixed, while that of r_2 turns upon its axis, the arm r which opens and closes the local circuit of the register or sounder, being attached rigidly. When the poles of the two magnets r_1 and r_2 attract each other, the arm r is pressed against the stop p, and the local circuit is closed, but when the attraction ceases, or is succeeded by a repulsive action, the spiral spring acts, drawing down the arm r opening the local circuit. The action of the apparatus is as follows:—The main batteries B at the two terminal stations are perfectly arranged with their negative poles to the line, as shown in Fig. 30. In the normal position of the apparatus these neutralize each other, and there is no attraction between the poles of the magnets r_1 and r_2 of the relay R. If now the key K is depressed, the battery B at the home station is reversed; its polarity then coincides with that of the battery at the distant station, and the combined current of both batteries traverses the line producing a corresponding magnetic effect in the coil r_1; at the same instant the equating circuit is closed at k, and the current of the equating battery b, traverses the other coil r_2, giving it an equal and opposite magnetic polarity, in consequence of which the home relay is unaffected by the depression of the key at the same station. When the key at the remote station is depressed, and the home key is not, the relay responds because the equating current is absent in the coil r_2. If the home key be depressed, the depression of the distant key causes the main batteries to oppose each other, in which case the signal at each station is given by the action of its own equating battery. By an obvious modification of this plan, the equating circuit might be taken from the main battery B, dispensing with the special battery. In Farmer's arrangement, the continuity of the main circuit is never interrupted, and the resistance of the circuit remains the same, whatever may be the position of the key.

Fig. 31 is of the principle of W. H. Preece's method. Its characteristic consists in the balance upon the relay of the home station being effected, not by two branch currents of the same battery, but by the entire current in one direction, and a branch of the entire current coming from the other direction. If the relay R of Fig. 31 is wound with two separate and equal wires, and the branch line c W a disconnected, then any current sent to line by the depression of the key T, or any incoming current from the line L, passing to the earth through the back contact 3 of the key, would have no effect upon the armature of the relay. If the branch *c* W *a* be connected, having a resistance equal to that of the line L beyond the point *c*, and the key T be depressed, the entire current of the battery B would pass through the left-hand coil of the relay, while only one-half of it would pass from the point *c* to line through the opposing coil, the remainder going to earth by way of *c* W *a*. On the contrary an incoming current would also divide at *c* in the inverse proportion of the resistance *c* V *a* and *c* W *a*, and the portion passing by way of V would nearly counteract the effect of the undivided current in the other coil. The problem is to weaken as much as possible the effect of the undivided current in the left-hand coil of the relay at the sending station, together with that of the arriving current in the same coil, which tends to prevent the relay from giving signals by counteracting the effect of the other coil. In practice this result is effected by the use of a Siemens polarized relay, the wire *a* W *c* being connected at a point *c*, between the two coils, which are so wound as to oppose each other, when a current is sent through them consecutively in the ordinary manner. With this arrangement, it is only necessary to remove the adjustable pole-piece of the left-hand coil to a greater distance from the armature than the right-hand one to effect a balance, so that the relay will respond to incoming currents, but will not be affected by outgoing currents.

Fig. 32 is a complete plan of the arrangement of Frischen's system at both stations, distinguished by the letters A and B. The main batteries L B at each station are placed with their positive poles to the line, and the negative poles to the earth. R and R^1 are the receiving relays, each wound with two separate coils. The rheostat, W or W^1, in the artificial line at each station, must be so adjusted as to make its resistance exactly equal to that of the line A B, added to that of one wire of the relay at the distant station. If the key at station A is depressed, the current from the main battery L B will divide at the point 3, one portion going by way of 4 and 6 to the line, passing through one coil of the relay, thence from the line through one coil of the relay at the distant station B, by way VI. and IV., thence by III. and II. to the key lever at *b′*, back contact *c′* and wire XI. to the earth, the other portion going from 3 in an opposite direction, through the home relay by way of 7, 8, rheostat W, and wires 9, 10 to the earth. These two branches of the current will be equal to each other, and will produce no effect upon the relay at A for that reason. The relay at B, on the other hand, will be affected by the current coming from A and will respond to the movement of the key at the latter station.

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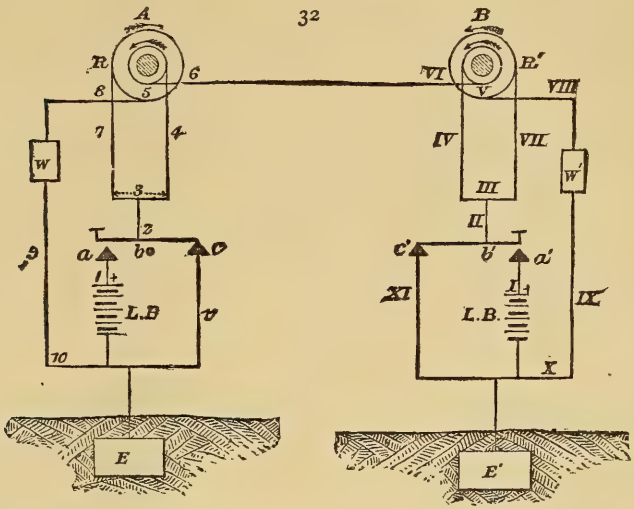
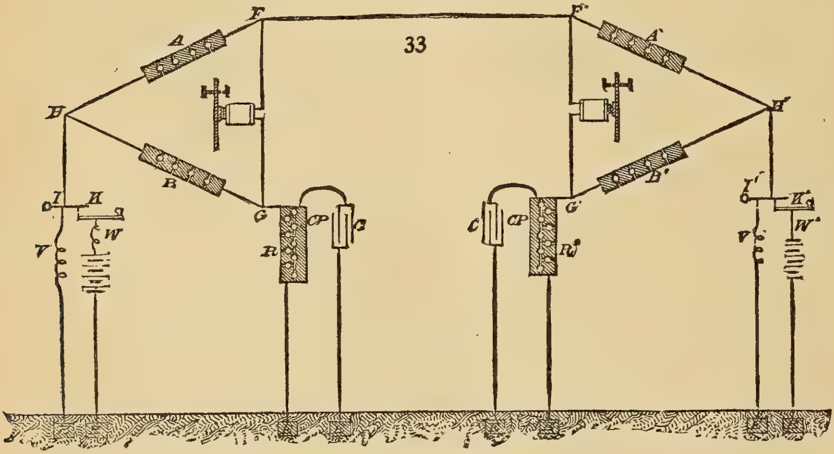


If now the key at B be also depressed, one half of the battery current tends to go to the line, but as it meets the current from A of opposing polarity, the current in the main line is neutralized or becomes nil. The current in the artificial line at each station being no longer opposed by the line current, will operate the respective relays, and the signals given will correspond to the length of time the key is depressed at the opposite station. Thus each station receives its signal through the action of the distant battery only.

A third position occurs when one of the sending keys, for instance, at B, is in the act of changing from the rear contact *c'* to its front contact *a'*, in which case the current from A is interrupted at *b'*, and is, therefore, forced to pass through the second coil of the relay, but this time in the same direction, and thence through the rheostat W' to the earth. The current arriving at B is weakened one-half in consequence of the additional resistance encountered at W', but this is compensated for by its passing through both coils of the relay at B, in the same direction, and its total effect upon the relay is not lessened. The difficulty in this connection arises from the fact that when the current at the receiving station is thus momentarily made to traverse both coils of the relay, together with the rheostat, it necessarily causes an unequal division of the current between the two opposing relay coils at the sending stations, as the resistance of the main line becomes about double that of the artificial line, and thus the sender's relay is affected. As this occurs always either at the beginning or the end of a signal, no actual inconvenience is experienced, except possibly when the transmission is unusually rapid. A peculiarity of this, in common with many other methods of simultaneous double transmission in opposite directions, consists in the fact that it may be operated with equal facility, when the main batteries are arranged with agreeing instead of opposing poles.

Fig. 33 is of Stearns's bridge duplex. H, A, B represent the apparatus at either end. In this diagram the line L constitutes one side of the balance, the resistance coil or rheostat R, the opposite side, while the other two sides are formed by two branch circuits A and B. The receiving instrument is placed in the bridge between F and G. The two branch circuits unite at H, and are connected by a wire to the lever I of key K. When the knob of the key is depressed, a current is sent along the wire to H and there branches, a portion passing through resistance coils A to line L, and a portion through resistance coils B and R to the earth.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If the resistance of the branch A bears the same proportion to that of L, as the resistance of B bears to R, then no currents will pass through the relay. When a current from the distant station is sent to line, a portion of it passes through the receiving instrument in the bridge, for, at the point F it finds two paths to pursue, one through the resistance A to the lever *l*, and small resistance *v* or *w* and battery to the earth, and the other through the relay and coils B and R to earth.

The key K is so arranged that the line is always connected to the earth, either through the back contact direct, or through the front contact and battery: *v* and *w* are small resistances placed in the circuits to prevent the battery being put even momentarily on short circuit, and also for the purpose of maintaining a uniform resistance in the circuit when the line is connected to earth direct, or through the battery. C is a condenser, for compensating the static charge from the line, and is attached by a wire to a brass plate C P, on the rheostat R, which is provided with plugs for connecting it with the

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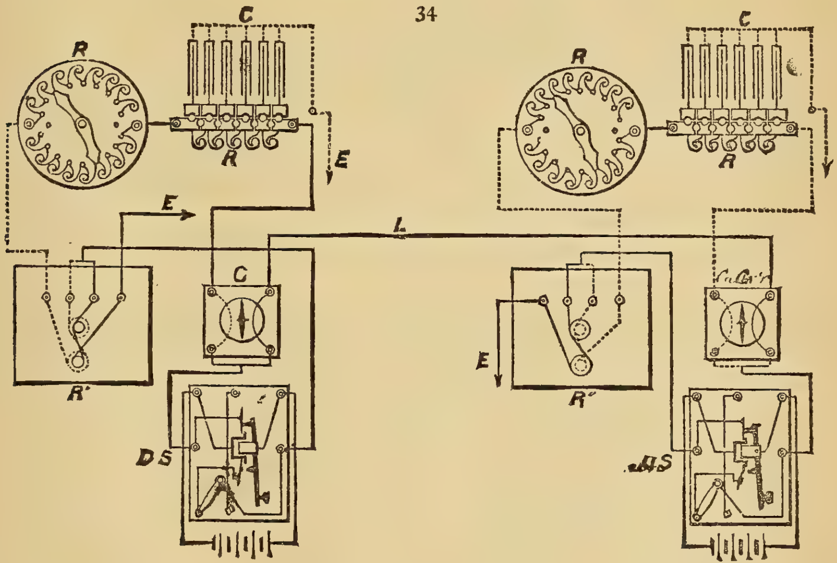

resistance coil plates, by which the condenser charge can be sent through any portion of the resistance coils as desired. The method suggested by Frischen, in 1863, in which he proposed to employ differential polarized receiving instruments, and arrange the key so as to send reversals, has been adapted to Stearns's apparatus in England. Fig. 34 is the arrangement of the apparatus. The key is provided with a switch, so that the battery may be disconnected when not required for working. A differential galvanometer G is employed for convenience in balancing the resistances with accuracy. The rheostat coils R are arranged in a circle, and contact is made by means of two arms resembling the hands of a watch, one of which is connected to the higher and the other to the lower resistances. A series of retardation coils connect R with the condenser C, so that its return discharge may be graduated to correspond with that from the line. R″ is a Siemens polarized relay with differential helices; L line, E earth, U S the up station, D S the down station.

In Smith's electro-mechanical method, Fig. 35, M is the receiving relay, which operates the sounder S in the usual manner by means of the local battery I. The armature lever A of the relay turns on an axle at *a*, and plays between the front and back contact stops *b* and *c*. D is a contact lever having its fulcrum at *d*. When the transmitter T is in its position of rest, its projecting arm *t* is in such a position that the arm D is drawn against it, by the tension of the adjustable spiral spring *s*, and is, therefore, in electrical contact; but when the armature of the transmitter is depressed, the arm *t* is withdrawn, and the lever D falls back, by the tension of its spring *s*, against the projecting stop a_1 of the relay armature A. The connections are arranged as follows:—One pole of the main battery E is connected to the fulcrum *a* of the relay armature A, and the other pole to earth at G. The fulcrum of the transmitter T is also connected to earth, a spark coil *r* being inserted, equal in resistance to the battery in the usual manner. The line L goes first to the helices of the relay M, and thence to the fulcrum of the contact lever D.

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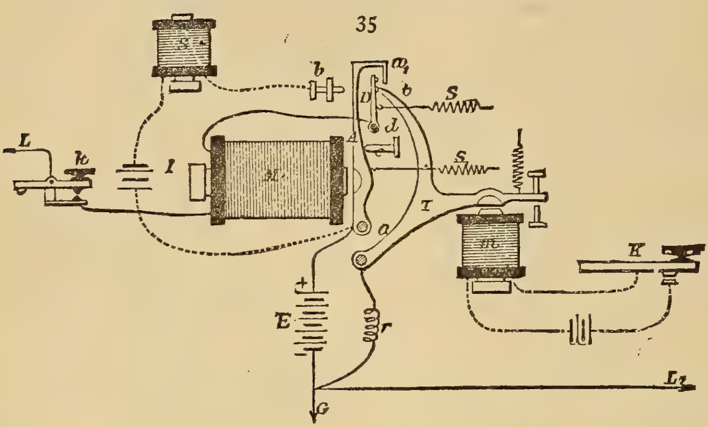

The transmitter T may be worked directly by hand in the same manner as an ordinary key, but it is preferable to arrange it in the ordinary way with a local magnet *m* and key K.

The diagram represents the normal position of the apparatus when not in use. The armature spring s_1 is adjusted to correspond to the incoming currents. When the home station has its key K open, the relay and sounder respond to the writing of the distant operator. The currents entering at L pass through the relay M, and thence find their way to the earth by way of the contact lever D, transmitter T, and spark coil *r*. The upper spring *s* is so adjusted that when acting in conjunction with the spring s_1 their combined pull will hold the armature lever A in its back stop *c*, with sufficient force to withstand the attraction produced in the relay magnet M by the action of the main battery E, either at the home or the distant station alone, but the combined effect of the two batteries, when both of them are in circuit at the same time, will be sufficient to overcome the combined tension of the springs without difficulty. When the armature of the transmitter T at the home station is depressed, the arm *t* is drawn back; and the spring *s* pulls the contact lever D against the stop a_1 of the armature lever A, which connects the main battery E to the line through the home relay M, but at the same time the combined tension of the two springs *s* and s_1 is exerted to prevent the armature from responding.

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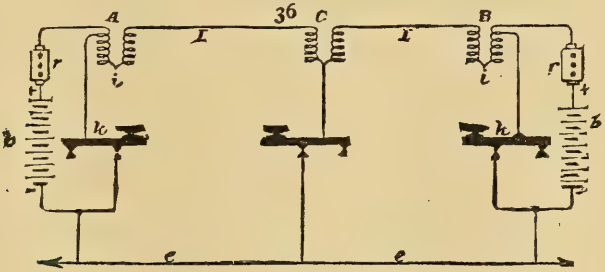
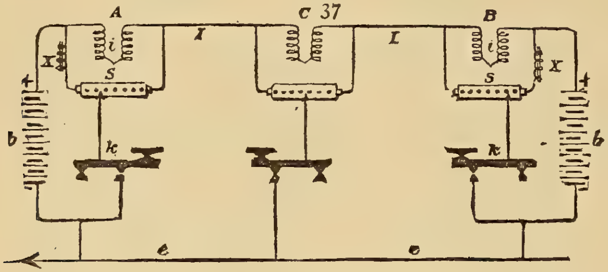


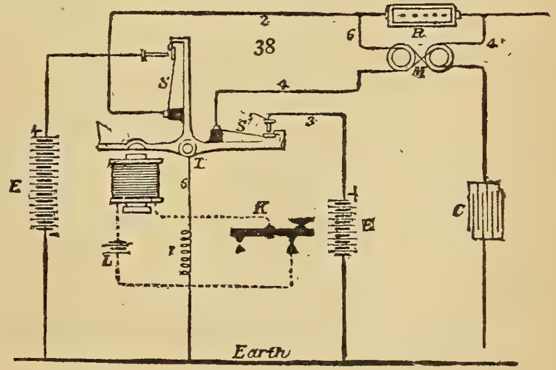
If the distant key is depressed, and the battery of the distant station also placed in circuit, the tension of both springs is overcome, the armature A responds to the increased attraction of the magnet M, and closes its local circuit at *b*, thus recording the signal from the distant station. It is necessary that the main batteries should be placed with unlike poles towards each other, as in the ordinary closed circuit system.

Fig. 36 is of Winter's method. A and B represent the two terminal stations; I is the line between them. At each station *i* is the receiving instrument, *k* key, *b* battery, *e* the earth connection, and *r* a resistance coil. Suppose one-tenth of the wire of the instrument is between *k* and *r* and nine-tenths between *k* and I; let the resistance *r* be nine-tenths that of the line, and let the insulation of the line be supposed perfect. If, now, the key at A is depressed, the battery *b* is on short circuit through the resistance and one-tenth of the instrument. The current from the battery at B flows through the whole of the instrument at B, the whole of the line wire and nine-tenths of the instrument at A. Its action upon the instrument at A is antagonistic to that of the battery acting locally at that station, and it has to go through about nine times the resistance; it has only about one-ninth of the strength of the current of the battery on short circuit at A, but as it has nine times as many convolutions of the instrument wire to pass through, the actions are just balanced, and the instrument at A is unaffected. At B, however, it is evident that the battery acts on the whole of the coil of the instrument, and produces a signal accordingly, which is only slightly weakened by the insertion of the resistance *r*. When B communicates with A, matters are simply reversed. When both keys are depressed at once, the battery at each station acts locally, and the action on each instrument is only about one-tenth less than the action of the whole of the battery, when, after traversing the line, it acts upon the whole of the coil of the instrument as in single sending.



With another but less effective method by the same inventor, Fig. 37, the key, instead of being connected to a point in the wire in the interior of the instrument coil, is joined to a point in a resistance *s* acting as a shunt on the receiving instrument, much nearer to the battery end of the shunt than the line end. A suitable proportion between the resistance *s* and the instrument coils is 4 or 5 to 1. The point where the key is connected may, if required, be made adjustable by means of a sliding contact. Both the above arrangements can be applied to intermediate instruments very simply, by making the point where the key is connected nearer to the middle of the instrument coil in the first arrangement, and of the shunt in the second method. The intermediate stations can then communicate with each other, or the terminal stations, in duplex, and without batteries.

The effect of the static induction of the line in the opposed battery system is as follows:—When both keys are in their normal position, the potential of the whole line is raised or lowered by the opposing batteries above or below that of the earth, and the line will in consequence hold a charge which will depend for its quantity upon the inductive capacity of the line. When either of the keys is depressed, the potential of the circuit at that point will be the same as that of the earth, and half the charge of the line will flow out through the line coil of the instrument. In the second of the two systems, Fig. 37, the effect of the charge and discharge will be lessened by part being carried off by the shunt. At each depression of the key, a strong instantaneous current is flowing in one direction through the line coils of the instrument, and when the key is raised there is another instantaneous current flowing in the opposite direction through the whole coil. The effects of the discharge, when not compensated, are, on the whole, much less marked in this than in the open circuit system. Winter's method of effecting the compensation for the inductive discharge is by winding the shunt on the battery side of the key upon an iron core, as at X, Fig. 37.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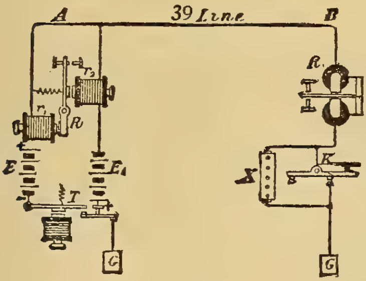
The transmitter T, Fig. 38, of G. Smith's electro-mechanical method, is worked either directly by the finger of the operator, or preferably, by a magnet, local battery and finger key K, as in the

Stearn's duplex. It is so arranged that the two batteries E and E^1 are both placed in circuit simultaneously whenever the key is depressed. The circuit of battery E when closed, passes through the wire 1, spring S of the transmitter T, wire 2, and rheostat R to the junction of wire 4 and the line, where it meets the opposing current from battery E^1, which comes through wires 3 and 4, including one wire of differential relay M. The current of the principal battery E is materially weakened by the resistance of the rheostat R, so that a much smaller battery E^1 is sufficient to oppose its tendency to find its way back to the earth through the wire 4 and relay M. It therefore goes over the line to the distant station, and operates the instrument at that point. Thus the first condition of duplex working is provided for, as the two batteries E and E^1 neutralize in the wires 3 and 4 and relay M. The currents received from the distant station, over the line, divide at the junction of the wire 4, one portion going to the earth through the rheostat R and wire 2, and the other portion through the wire 4 and relay M, recording the signal. So far as the strength of the outgoing current is concerned, it is quite immaterial what the resistance of the relay M is, and this may therefore be made of whatever resistance will produce the most favorable effect with the incoming currents.

An ordinary relay might be used with this duplex, but in practice it has been found preferable to substitute a differentially wound relay. The extra circuit of this forms a part of the wire 6, which is attached to the battery 2, and to one side of a condenser C, the other side of which is connected to earth. By this contrivance the return current or static charge is effectually compensated. When the circuit of the battery is closed, the condenser C takes a charge. When the battery is removed from the circuit, the line and the condenser discharge themselves simultaneously, but the two charges pass off in opposite directions through the two wires of the differential relay, and their effect upon its cores is nil. The resistance of the spark coil *r* should be made equal to that of the joint resistance of the batteries E and E^1. The balance of the whole system is obtained by varying the rheostat R.

Instead of a transmitter with the continuity preserving springs S S, an arrangement might be used which would short circuit both batteries when the key is up, by a connection which would be interrupted when the latter is depressed, so as to allow the current to flow to line.

In a method of simultaneous transmission, invented by T. A. Edison in 1873, Fig. 39, the signals are transmitted in one direction by reversing the polarity of a constant current and in the opposite direction by increasing and decreasing the strength of the same current. The relay R at station A consists of two soft iron electro-magnets r_1 and r_2, which act upon the same armature lever, closing the local circuit of the sounder or other receiving instrument in the usual manner. The transmitter T is operated by a key and local battery as in Stearns's method, and is so arranged that when the key is in a position of rest the negative current from the battery E_1 passes to line through the electro-magnet r_2 of the home relay R; but if the key is depressed, the lever T of the transmitter makes contact between the battery E and earth G, and at almost the same instant interrupts the previously existing contact between E_1 and the earth. There is at all times either a positive current going to line through r_1, or a negative current through r_2. At station B the currents pass through a polarized receiving instrument R_1, and thence through a rheostat X to the earth. The tension of the spring of relay R is adjusted, so that the current going to line is not sufficient to overcome it, except when the rheostat X is cut out by depressing the key K at station B. Consequently A sends to B by reversing the polarity of the current, without changing its strength, while B sends to A by changing the strength of the current irrespective of its polarity. The polarized relay can be placed at a number of stations on the line, and each will be able to receive the signals from the stations transmitting the positive and negative currents. A neutral or Morse relay may also be placed at a number of stations, if devices are employed to prevent the mutilation of the signals by change in the polarity of its iron core.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The principle embodied in this invention has been successfully employed in quadruple transmission, by modifications in the arrangement of the apparatus.

Vianisi has invented a system for duplex working, based on the Poggendorff bridge. Both systems agree in the arrangement of the batteries so far, that the balance is obtained in the circuit containing the one battery, and differ in that Vianisi chooses as line, the circuit containing the second battery. Calculation proves that both electrical systems suffer from the disadvantage that the portion of the current entering the line is comparatively weak. One of the nine combinations of the system designed by Vianisi differs from the others in effecting the balance in the receiver of the sending station, by means of a current coming from the receiving station, consequently each station requires but one battery.

When neither key is depressed, both batteries are closed, but since similar poles are connected to the line, the currents, being equal and opposite, do not produce any effect. When station I is sending, its own battery is short-circuited through I's receiver. When both I and II send, each battery acts upon its own receiver, the currents passing through the line, neutralizing one another.

The basis of the system is explained as follows: Let Fig. 40, the opposite poles of two batteries, B_1 and B_2, whose electro-motive forces are equal to E_1 E_2, be connected by wires, and let a suitable receiver be connected at two points, *a* and B. If the strength of the currents in the three branches be indicated by J_1, J_2, J_3, and the resistances by W_1, W_2, and W_3, according to Kirchoff's laws there will be obtained

$$J_1 - J_2 - J_3 = 0.$$
$$E_1 = J_1 W_1 + J_3 W_3.$$
$$E_2 = J_2 W_2 - J_3 W_3.$$

From these equations the following values may be deduced:—

$$J_3 = J_1 - J_2.$$

$$J_1 = \frac{E_1 - J_3 W_3}{W_1} = \frac{E_2 + J_3 (W_2 + W_3).}{W_2}$$

$$J_2 = \frac{E_2 + J_3 W_3}{W_2} = \frac{E_1 - J_3 (W_1 + W_3)}{W_1}$$

Obviously, $J_3 = 0_1$ if $E_1 W_2 - E_2 W_1 = 0$.

The equations are of use when one station is sending but not receiving. Figs. 41 to 43 are modifications of the method.

The key, Fig. 44, when depressed, breaks two circuits and establishes two new ones without interrupting the line. Two auxiliary levers *b b'*, Fig. 45, are added to the ordinary key lever. These are insulated from the main lever by ebonite plates, which are movable around the axes *e* and *e'*. At rest, the auxiliary levers, by the forked spring k and k_1, which may be tightened at will by means of a screw i, are pressed upon the insulated contact pieces c and c'. The arms k k_1 of the spring are not in metallic contact with the auxiliary levers, and they press against the plates of ebonite l l. The metal plates n and n', are screwed firmly to the bottom of the apparatus below the auxiliary levers, and they have attached to them movable contact pins. If the key be pressed down, the auxiliary levers b and b' come into contact with the studs d and d'; and if the pressure on the key be continued, they are raised finally off the points of contact c and c'. If the key be allowed to rise again, then b and b' come into contact with c and c', and only b and b' break contact with d and d'.

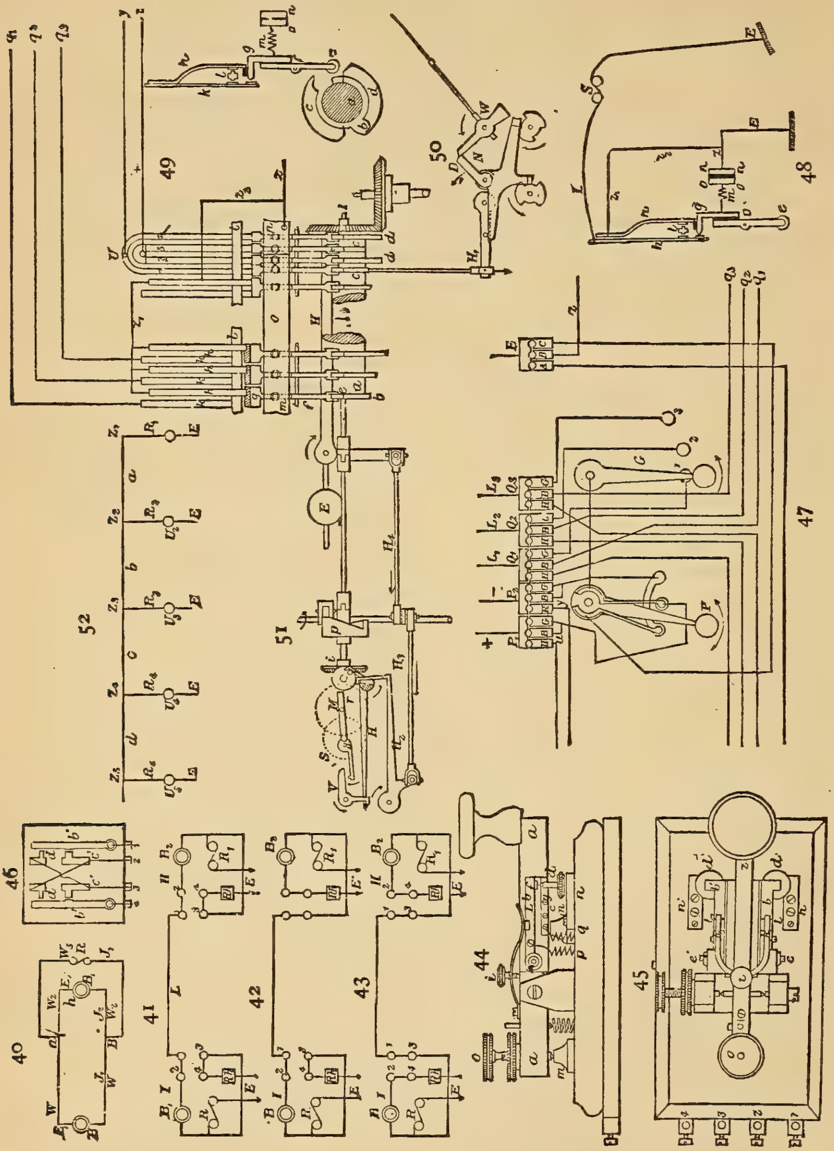
The connections of the binding screws 1 to 4 become clear from Fig. 46. At rest, the terminals 1 and 2 are in metallic connection by b and c; also the terminals 3 and 4 by b' and c'. When the key is depressed, a current entering at 1 flows to 3 by b, d, and c', and a current entering at 2 flows to 4 through c, d' and b'. During the motion of the key no interruption occurs, except a short circuiting of the battery, as the connections b, d, and b' d' are established before the contacts between b, c, and b' c' are removed.

The adjustment of the apparatus is simple. The studs d and d' should be equal in height. When the key is in use, care must be taken not to injure the thin spiral wires p and q, Fig. 44, which establish the connection between the auxiliary levers and contact pieces with the binding screws. Fig. 46 is a plan of the key connections.

In the plans of the circuits, Figs. 41 to 43, the key is indicated by the four terminals connected in pairs. The rheostats *Rh* allow an insertion of from 1 to 4000 units. The receivers R, R_1 are Morse ink writers with movable electro-magnet and double springs. The battery consists of a modification of Meidinger elements.

When both keys are at rest.—At each station 1 and 2, 3 and 4 are connected: both batteries B have copper to line, with zinc, through receiver and resistance, to earth E. As the two opposed currents are of equal strength, the line, completely insulated, is free from a current.

Key at station II pressed down; at station I at rest. At II the points 1 and 3, 2 and 4 are connected: at I, as before, 1 with 2, and 3 with 4. The positive current of battery B goes through line L to II, flows through two parallel branches, through the receiver R_1, the resistance, and returns through earth to I through the parallel branches Rh_1 and Rh_2. But the receiver of the sending station II is influenced at the same time by its own battery, the positive current from which enters from below through Rh, into the Morse R_1;



thus a balance of the two opposite currents may be effected in R_1. The plan, Fig. 41, appears to be identical with Fig. 42. W_1 of the equation, is represented by the combined resistance of line L of battery B, of the branches R and *Rh* and of the earth; W_2 by B_2 and resistance *Rh;* and W_3 corresponds with the resistance of the writing instrument R_1 of the sending station. If $W_1 = W_2$, E_1 being henceforward taken as equal to E_2, then, according to the equations, the receiver R_1 would remain entirely free from a current. This is not always the case; sometimes a weak current passes through the Morse instrument of the single sending station, and this current is not sufficiently powerful to attract the armature.

Both keys depressed.—The points 1 and 3, 2 and 4 are connected at both stations. The positive current passes in both stations through rheostat and receiver to the zinc pole. The zinc pole of both batteries is connected to line; therefore the currents neutralize each other in the line.

As a practical example as to the difference existing between the single and duplex signals, let there be given the resistance of the line equal to 1200 units, that of the receiver as equal to 400 units, and let the resistance in each rheostat be 1600 units, equal to line + receiver inserted. Resistance of the earth = 0. At each station are placed 18 Meidinger cells, of which the combined electro-motive force = 18, and total resistance = 108 units.

According to the equations,

$$W_1 = 1628\,;\ W_2 = 1708\,;\ W_3 = 400.$$

$$J_3 = 0{\cdot}00035\,;\ J_1 = 0.0109\,;\ J_2 = 0{\cdot}0106.$$

As the rheostat *Rh* is arranged as a shunt for the receiver, only $\frac{4}{5}$ths of the current pass through the receiver, and $\frac{1}{5}$th through the rheostat, the ratio of the resistances of both parallel being as 1 : 4; from this

$$\tfrac{4}{5}\,J_1 = \tfrac{4}{5} \times 0{\cdot}0109 = 0{\cdot}0087.$$

Let the magnetic moment of the receiving magnet be equal to the strength of current, multiplied by the square root of the magnet's resistance, then we have

$$M_1 = \tfrac{4}{5}\,J_1 \sqrt{W_3} = 0.0087 \times 20 = 0{\cdot}1740.$$

The receiver of the sending station receives a magnetic moment, 20 J_3 or 0.00700, which is incapable of producing any effect.

In case 3, for each station, $J = 0{\cdot}0085$; $M_3 = 0{\cdot}0085 \sqrt{400} = 0{\cdot}1700$.

The difference of the magnetic moments in cases 2 and 3 is $D = 0{\cdot}004$, consequently the single and duplex signals are almost of equal strength.

In Vianisi's first arrangement, the terminals 3 and 4 were insulated when the key was at rest, therefore the current acted with full force on the receiver at I, since the shunt R did not exist. Consequently W_1 could be made equal to W_2, therefore the current J_3 and magnetic moment in $R_1 = 0$.

In pursuance of the calculation with the numerical values given above, in case 2, the magnetic moment of the receiver R_1, $M_1 = 0.2100$.

In case 3, as above, $M_3 = 0{\cdot}1700$, and thus $D_1 = 0{\cdot}04$; that is greater than in the preceding instance.

Receivers of too great a sensitiveness will not work so accurately under these circumstances.

The difference between the simple and duplex signals in the first example can be further reduced by inserting a resistance coil of 40 units at each station between the terminal 4 and the line; then in case 2;—

$$J_3 = 0;\ J_1 = J_2 = 0{\cdot}0105;\ M_1 = \tfrac{4}{5} J_1 = \sqrt{} W_3 = 0{\cdot}1680.$$

For case 3, as before stated, $M_3 = 0{\cdot}1700$, $D_2 = 0{\cdot}002$.

A small galvanometer or detector is inserted between the receiver and the earth. The resistance of it, 2·5 units, has to be considered in the numerical examples.

The receiver of the sending station shows inertia. For trial, I is arranged as in Fig. 40. The receiver was at first a Hipp's relay magnet; then a Siemens polarized relay; succeeded by a Hughes instrument. To make R work, the following alterations of W_1 were necessary: W_1 and W_2 were originally rheostats of 500 units each. 1st. $W_1 = 320$ units. 2d. $W_1 = 360$ units. 3d. $W_1 = 460$ units. In the last case, the Hughes magnet was adjusted to extreme sensitiveness.

This duplex method is applicable to the Hughes instrument, Figs. 47 to 51.

Vianisi's automatic repeater is a relay intended for transmission, whose contact lever interrupts two currents, and establishes two new ones. This relay is inserted in the local circuit of the sending Hughes instrument. The mechanical locking of the printing axis applied to the new Hughes telegraph affords a means for adapting

Vianisi's method. For this purpose, a system of auxiliary levers is applied to the contact lever of the sending Hughes, Figs. 48 to 51. The movable parts b, b^1 must work easily. The plan of insertion does not differ from that in Figs. 48 and 51.

A numerical example of the bridge method modified and applied to the Hughes instrument, will illustrate the principle.

Resistance of line, 80; of one Hughes, 20; of one element, 0·12, all the resistances being expressed in rheostat units, each equal to 50 Siemens units. The strength of current required to work a Hughes is 0·73, and 80 to 96 elements are requisite for single working.

Taking 100 elements. In case 2;—$J_3 = 0·0205$; $J_1 = 0·917$; $J_2 = 0.8965$.

As in the first example, the rheostat forms a shunt to the Hughes magnet, $\frac{5}{6}$ J will flow through the coils, or $\frac{5}{6} \times 0·917$; that is, 0.764. But when the armature of the receiving Hughes strikes the locking lever, the coils are short-circuited and the values are altered; and

$$J_3 = 0·139;\ J_1 = 1·056;\ J_2 = 0·917.$$

The current J_3, which flows through the receiving Hughes of the sending station, strengthens the induced magnetism of the cores, since it flows in a direction opposite to that which produces the signals at II. If, now, station I begins to send, a sudden reversal takes place in the magnet at station II.

Fig. 47 shows a Hughes connected with two batteries and two rheostats. Between P and P′ a key is inserted, whose depression suddenly breaks the circuit of the battery P. Having first made $W_1 = W_2$, W_1 is gradually diminished, which has the effect of strengthening the cores in R, and the sudden depression of the key causes the magnet to be acted on by P′ only. With the magnet adjusted, the locking of the printing axis is easily effected.

In case 3, the current acting on each Hughes is

$$J = 0·757,$$

and the difference of currents in cases No. 2 and No. $3 = 0·007$. J_3 could be made $= 0$, by the insertion of a resistance coil. There are 333 elements required to obtain a current of $J = 0·73$ in the previous example; but the bridge method is applicable to both old and modern Hughes instruments without auxiliary mechanism.

Fig. 52 is self-explanatory of the means of connecting intermediate stations.

M. Sieur's duplex system is distinct in principle. It is based on the use of a distributor or automatic current reverser, which divides up the time of sending into a series of small and equal intervals, during which a succession of alternating positive and negative currents, each current occupying an interval, are sent into the line. These currents are received separately on two polarized relays, one relay responding to the positive and the other to the negative currents. The system admits of sending two messages in the same direction simultaneously, or two messages in contrary directions. The distributor is the same in either case, and consists of a cam D, Fig. 53, connected to earth and turning by clockwork between two steel springs C Z, which it raises alternately as it rotates. If the cam revolves at a speed of twenty turns a second, it will raise during one-fortieth of a second the spring C, and being in contact with earth, it will put the positive pole of the battery to earth during that time, whilst the negative pole, through the spring Z, is in connection with the stud P of the key B. Passing on from the spring C, which returns to its stud A, the cam raises the spring Z, breaking contact with B. The negative pole of the battery is thus put to earth while the positive pole is connected to the stud P of the key A. During each revolution of the cam, the two poles of the battery are thus alternately drawn upon, but the intermittent currents from each are led to separate signalling keys A and B. If the key A alone is manipulated, a positive intermittent current is sent into the line, the interruptions succeeding one another at intervals of one-fortieth of a second. If the key B be worked a series of similar negative currents enter the line.

The receiver is a polarized relay with two armatures, the armature A only answering to positive currents, and the armature B to negative currents. Two polarized relays with a single armature will serve the same purpose. The armature B, which can only act under the influence of the negative current, remains passive on its upper contact, short-circuiting the local battery which actuates the recorder B; but the armature A is attracted by the positive currents into contact with its lower stop; breaking the short circuit and enabling the local battery to signal on the recorder A. The armature A is only attracted for one-fortieth of a second at intervals of one-fortieth of a second, but the recorder A can be so adjusted as to bridge over the interruptions, and give entire signals, while the key A is depressed, just as if the current were continuous. In the same way, when the key B is manipulated, the recorder A is passive, while the negative intermittent current from B attracts the armature B, breaks the short circuit, and allows the recorder B to signal. If both keys operate together in sending two different messages simultaneously, both armatures will simultaneously respond, each to its respective key, and both recorders, each to its respective armature.

In the arrangement considered, the armatures in vibration are caused to actuate the recording instruments, but by another method, Fig. 54, they can be made to signal when at rest. Instead of connecting the springs of the distributor to the studs P of the keys, they are connected in this case to the studs *r* on which the lever of

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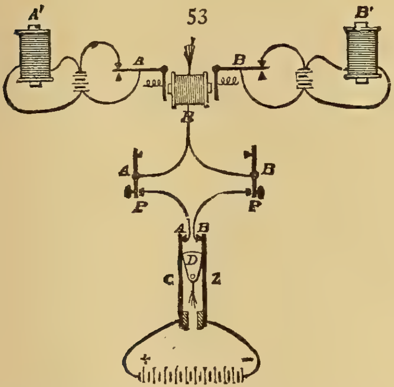

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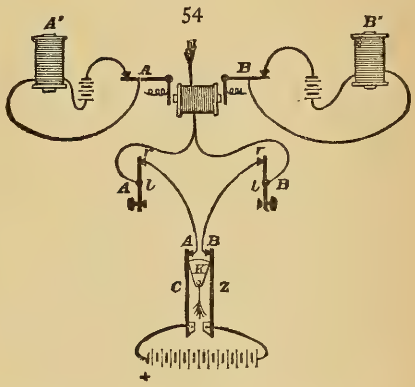

the key bears when at rest. A series of intermittent currents are in this way continually flowing into the line, positive from the key A, negative from the key B. These currents cause the corresponding armatures of the relay to vibrate continually. The local recording circuits are so joined up to the armatures, as to be closed when the armatures are at rest on the upper stops, and open when the armatures vibrate, for the rapidly intermitting currents cause the armatures to vibrate freely midway between both upper and lower stops. On depressing the key A, contact is broken at *r*, the positive current ceases to flow and the armature to vibrate. It returns to its rest stop, completes the local circuit, and causes the recorder A to signal. Similarly the key B causes the recorder B to signal; and when both keys act at once, both recorders respond together, each to its proper key.

When sending two messages in contrary directions, each station must be able to send a message without interfering with its own receiving instrument. Let the two stations be called respectively S and S′. Only the station S is provided with a distributor, and it is of the form shown in Fig. 54, that is, the wires from the middle of the keys *l* unite; but before entering the line they are connected through the receiving relay. Fig. 55 is the arrangement of apparatus at station S′. The relay at both stations is so joined up, that the armatures A vibrate under the negative currents from S, and the armatures B, under the positive currents. The levers *m*, *n* of the signaling keys are each made in two metal parts insulated from one another. In the position of rest, the distributor of the station S sends into the line a series of alternating currents, which traverse the relay at S, and also that of S′, where they flow to earth by the levers *l* and the contacts T of the keys A_1 and B_1. At both stations the armature A and B of the relays oscillate, but have no action on their recorders.

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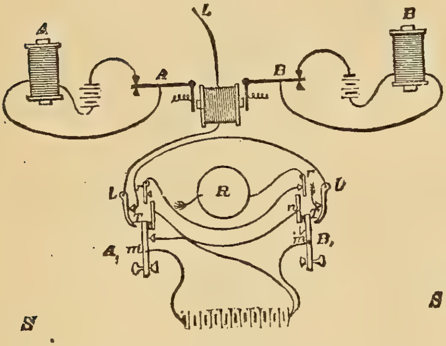

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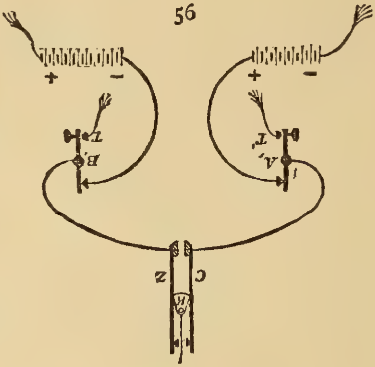


When the key A_1 at station S, Fig. 55, is alone depressed, the armatures A at both stations stop vibrating, and the corresponding recorders signal. Similarly when B_1 is depressed the corresponding recorders at both stations also signal. Hence the sending of station S operates both relays and recorders.

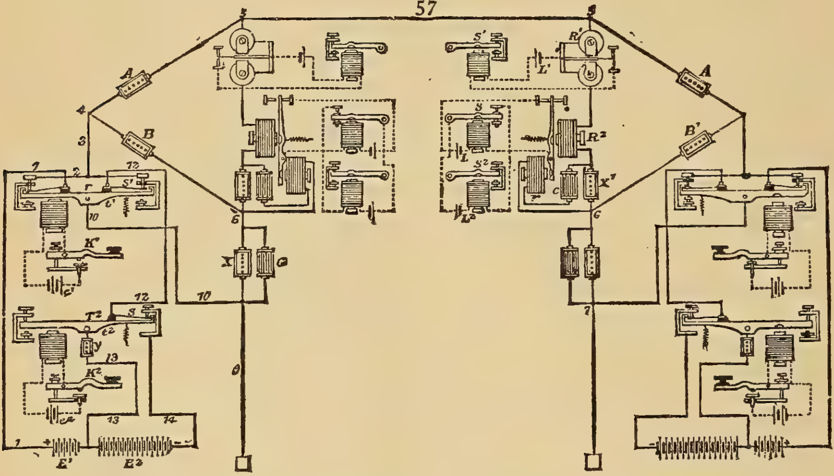
When the key A_1 of station S, Fig. 55, is alone depressed, the part *m* of the bar makes contact with the lever *l* and raises it, while the part *n* raises the lever *r*. The negative current from the battery reaching the part *n*, passes by the lever *r* or the key A_1, the contact piece, and the lever *r* of the key B_1, and goes to earth through the rheostat *R*, whilst the positive current passing by the part *m* and the lever *l* of the key A_1 enters the line. These positive currents from S′ strengthen the negative currents from S; but the rheostat *R* in circuit, is adjusted so as to reduce the intensity of the current so produced, to the intensity of a single negative current. The negative currents from S, therefore, act as if the key A_1 of station S′ were at rest, and the armatures B at both stations continue to oscillate. Conversely the positive currents from S are neutralized by the positive current sent into the line from S′; and consequently the armatures A at both stations cease to oscillate, thus actuating the recorders. If the key B_1 of the station S′ transmits alone, the part *m* of the bar raises the lever *l*, while the part *n* raises the lever *r*. The positive current, passing by *m* of the key A_1 and its resting stud T, to *n* of the key B_1, and the lever *r*, goes to earth by the rheostat *R*, whilst the negative current, passing by *m* and the lever *l* of B_1, the contact T and lever *l* of A_1, enters the line, where it does not affect the positive currents from S, but neutralizes the negative currents. At both stations, therefore, the armatures A continue to oscillate, but the armatures B are stopped. When both keys of station S′ act together, the positive pole of the battery is connected to the line by the part *m* and lever *l* of the key A_1. But the negative current, passing by the part *m* and lever *l* of the key B_1 is insulated at the contact T of the key A_1; and the same pole passing by the part *n* and lever *r* of the key A_1 is insulated also at the contact piece of the key B_1. There is consequently a breach in the line circuit, and the armatures of both the relays act, and both the recorders signal.

When the key A_1 or station S transmits at the same time as the key B_1 of station S′, the depression of the former suppresses the emission of positive currents from S, while the depression of the latter sends over the line a negative current which neutralizes the negative currents issuing from S; consequently there is no current on the line, both the armatures stop, and the recorders signal. The same effect takes place, but by an inverse process, when the key B_1 of station S is depressed at the same time as the key A_1 of station S.

When the key A_1 of station S transmits at the same time as the key A_1 of station S′ or the key B_1 of S at the same time as the key B_1 of S′, because the positive current sent out by S′ does not affect the negative one from S, the stoppage of the positive current from S affects the armatures of the relays A at both stations, the same a if the key A_1 at station S had not been depressed. Similarly the effect of depressing the key B_1 at station S′ while the key at station S is depressed is the same as if the latter alone was depressed, both B relays are operated.

Fig. 56 is of a method of simultaneous transmission by this system, in which separate batteries and ordinary contact keys are employed.

Quadruplex Telegraphy.—Fig. 57 is of Edison's quadruplex apparatus upon the bridge plan. r is a double current transmitter or pole changer, operated by an electro-magnet, local battery e^1, and finger key K^1. The office of the transmitter r is simply to interchange the poles of the main battery E^1, with respect to the line and earth wires, whenever the key K^1 is depressed; or, in other words, to reverse the polarity of the current upon the line by reversing the poles of the battery E^1. By the use of properly arranged spring contacts, s^1 s^2, this is done without at any time interrupting the circuit. Thus the movements of the transmitter r cannot alter the strength of the current sent out to line, but only its polarity or direction. The second transmitter T^2 is operated by a local circuit, and the key K^2 in the same manner. It is connected with the battery wire 12 of the transmitter r, so that when the key K^2 is depressed the battery E^1 is enlarged by the addition of a second battery E^2 of two to three times the number of cells, by means of which it is enabled to send a current to the line of three or four times the original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strength, but the polarity of the current with respect to the line still remains as before under control of the first transmitter *r*.

At the other end of the line are the two receiving instruments, R^1 and R^2. R^1 is a polarized relay with a permanently magnetic armature, which is deflected in one direction by positive, and in the other by negative currents, without reference to their strength. This relay consequently responds solely to the movements of key K^1, and operates the sounder S^1 by a local circuit from battery L^1 in the usual manner. Relay R^2 is placed in the same main circuit, and is provided with a neutral or soft iron armature. It responds with equal readiness to currents of either polarity, provided they are strong enough to induce sufficient magnetism in its cores, to overcome the tension of the opposing armature spring. The latter is so adjusted that its retractile force exceeds the magnetic attraction induced by the current of the battery E^1, but is easily overpowered by that of the current from E^1 and E^2 combined, which is three or four times as great. Therefore the relay R^2 responds only to the movements of K^2 and transmitter T^2.

A difficulty occurs when the polarity of the current upon the line is reversed during the time in which the armature of R^2 is attracted to its poles, for the armature will fall off for an instant, owing to the cessation of all attractive force, when the change of polarity is actually taking place, and this would confuse the signals by false breaks, if the sounder were connected in the ordinary way. By the arrangement shown in the figure the armature of the relay R^2 makes contact on its back stop, and a second local battery L^2 operates the receiving sounder S_2. Thus when relay R^2 attracts its armature, the local circuit of sounder S^2 will be closed by the back contact of local relay S; but if the armature of R^2 falls off, it must reach its back contact, and remain there long enough to complete the circuit through the local relay S and operate it before the sounder S^2 will be affected. But the interval of no magnetism in the relay R^2, at the change of polarity, is too brief to permit its armature to remain on its back contact long enough to affect the local relay S, and through the agency of this ingenious device the signals from K^2 are properly responded to by the movements of sounder S^2.

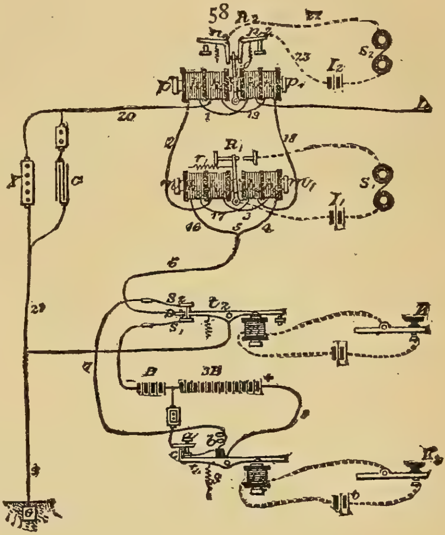
By placing the two receiving instruments R^1 and R^2 in the bridge wire of a Wheatstone balance, and duplicating the entire apparatus at each end of the line, the currents transmitted from either station do not affect the receiving instrument at that station. The duplicate parts which are not lettered operate in precisely the same manner, but in the opposite direction with respect to the line.

In applying this system of quadruplex transmission upon lines of considerable length, it was found that the interval of no magnetism in the receiving relay R^2 which takes place at every reversal in the polarity of the line current, was greatly lengthened by the action of the static discharge from the line, so that the employment of the local relay S was not sufficient to overcome the difficulties. A rheostat or resistance X^1 was therefore placed in the bridge wire with the receiving instruments R^1 and R^2, and shunted with a condenser *c* of considerable capacity. Between the lower plate of the condenser and the junction of the bridge and earth wire, an additional electro-magnet *v* was placed, acting upon the armature lever of the relay R^2, and in the same direction. The effect of this arrangement is, that when the current of one polarity ceases, the condenser *c* immediately discharges through the magnet *v*, which acts upon the armature lever of relay R_2, and retains it in position for a brief time before the current of the opposite polarity arrives, and thus serves to bridge over the interval of no magnetism between the currents of opposite polarity. The combination of transmitted currents in this method differs materially from any of those used in other inventions. They are as follows :—

When the first key is closed and the second open,	$+1$
When the second key is closed and the first open,	-3 or -4
When both keys are closed, ...	$+3$ or $+4$
When both keys are open, ...	-1

Another very important practical advantage in the system under consideration, is due to the difference or working margin between the strength of currents required to produce signals upon the polarized relay, and upon the neutral relay respectively, and this may be increased to any extent which circumstances render desirable. Within certain limits the greater this difference the better the practical results, for the reason that the range of adjustment of the neutral relay increases directly in proportion to the margin. The ratio of the respective currents has been gradually increased from 1 to 2, to as high as 1 to 4, with a corresponding improvement in the practical operation of the apparatus.

Before it became possible to produce a quadruplex apparatus capable of being worked at a commercial rate of speed upon long lines, it was essential that its component parts should have arrived at a certain stage of development. When, in 1872, simultaneous transmission in opposite directions was for the first time rendered practicable upon long lines by the combination therewith of the condenser, the first step was accomplished. It now only remained to invent an equally successful method of simultaneous transmission in the same direction, which was done in 1874.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G. Smith, in 1876, effected several important improvements in quadruplex telegraphs, Fig. 58. Both receiving relays R_1 and R_2 are provided with differential helices and polarized armatures, and in general the differential method is employed throughout in place of the bridge. The relays R_1 and R_2 may be constructed as shown in the figure, or according to Siemens' pattern. Experience has shown that the latter form gives, on the whole, the most satisfactory results, and it has therefore been adopted in all the more recent apparatus. The combination of the outgoing currents differs from that employed in the original quadruplex, and is as follows:—

K_1 open and K_2 open, current traversing line ..	$+4$ B
K_1 open and K_2 closed, ...	$+$ B
K_1 closed and K_2 open, ...	-4 B
K_1 closed and K_2 closed, ...	$-$ B

As in the original quadruplex, key K_1 controls the polarity of the current going to line, but the depression of K_2 decreases the outgoing current, irrespective of its polarity, from 4 B to B, or, in other words, cuts off the battery 3 B altogether.

The action of the relay R_2 is that only requiring detailed explanation. When both keys are at rest the positive current of both batteries $+ 3B + B$ is passing over the line, and the polarized armature is pressed against the contact lever n_1, which yields, thus allowing it to separate from the contact lever n_2, and the circuit of the sounder S is broken. When K_1 is closed, the polarity of the entire battery upon the line is reversed, and the armature passes over to the other side and presses against n_2 in the same manner, so that the sounder S_2 cannot be operated by the stronger currents of either polarity. But the depression of the key K_2 in either case decreases the current, until it is unable to withstand the tension of the springs of the contact levers n_1 n_2, and thus the local circuit through the sounder S_2 is completed, and the latter responds to the movements of key K_2. On circuits exceeding 200 miles the sounder S_2 is preferably operated through a local relay. The combination of the outgoing currents in different positions of the keys is also re-arranged, as—

K_1 open and K_2 open,	current	traversing	line,	$+ B$
K_1 open and K_2 closed,	"	"	"	$+ 4B$
K_1 closed and K_2 open,	"	"	"	$- B$
K_1 closed and K_2 closed,	"	"	"	$- 4B$

An example of a totally different system of multiple transmission, is that based upon the principle of the division of a single current into rapidly recurring waves or pulsations, first attempted by Farmer in 1852, and used in Meyer's apparatus.

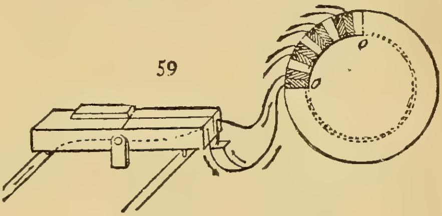
This system is intended to utilize all the currents that in a given time can be made to succeed each other in a wire, so that several operators, each sending twenty to thirty messages an hour, may transmit them upon the same wire.

The number of transmissions that a telegraph line will carry varies with its conducting power. It is generally admitted that, with a speed of twenty-five messages an hour, on a Morse instrument, about five pulsations of the current occur a second. Consequently, n being the sum of the currents which in a second can succeed each other in a conductor, $\frac{n}{5}$ represents the number of receivers which it is possible to establish upon a single wire, or the number of operators that can work at the same time.

The apparatus is usually constructed for four transmissions, and is worked by four operators. At a speed of seventy-five revolutions a minute, presenting four letters at each turn, it records one hundred messages an hour with twenty pulsations of the current a second. This is less than a maximum result, for experience has shown that telegraph lines can be worked at a much greater speed.

As the apparatus is arranged for transmission, four sets of keys, eight in each set, are placed with their receivers upon a table, each receiver having a continuous strip of paper for recording. A clockwork movement, actuated by a weight and regulated by a conical pendulum, serves as the motor of all the receivers. The keys, as well as the receivers, are connected with the earth wire, and with the line wire in the latter case, through the distributor.

The distributor, Fig. 59, is the principal part of the instrument. During four equal intervals of time it directs the current of the battery successively toward each of the four receivers of the receiving station. *o o* is a disc of metal, fixed and insulated. It has forty-eight divisions, twelve to the quarter of the circle, of which eight, grouped two and two, are connected to the earth. There are, thus, four cables of eight wires each, which start from the four sets of keys and end in the distributor. The groups or divisions are therefore sixteen in number, separated by intervals. The first half of a group, $\frac{1}{48}$th of a revolution, gives a short contact; the entire group to one of double the length. An elastic contact spring, mounted upon the axis, traverses the circumference of the disc, and successively connects the four keys and four receivers with the line, so that the current transmitted or received during the passage of the spring over one of the quadrants, is directed through the receiver to which it corresponds. Each operator thus has the line at his disposal during a quarter of a revolution. The transmitter is composed of eight keys, four black and four white, which are connected between the battery and the earth. The black keys represent dots, and the white keys dashes, starting from the left key. As soon as the rotating contact spring, in its movement, passes over that section of the disc to which the keys depressed are connected, the signal or letter is transmitted, the spring passing to the next quarter section, which is connected with the next set of keys, manipulated by another operator, and so on, with all the sections. Attached to each of the keys is an eccentric, the use of which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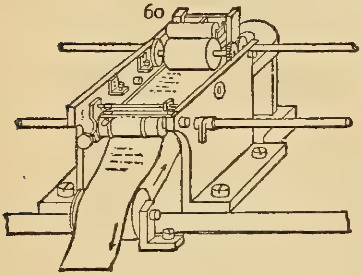
is to raise after each letter a smaller rider, and this, falling by its own weight, produces a tick, beating the measure, to which each operator works.

Each receiver has for its printing mechanism, Fig. 60, a section of a helix, resembling an elongated spiral. This may be more easily understood by supposing a cylinder having upon its surface a raised rib extending spirally over its entire length. As the contacts from the sets of keys are placed in a straight line over this cylinder, only one key can be put into connection with the spiral rib at the same time. The helix of the receiver and the rubbing contact of the distributor make their revolutions in the same time, and from the same starting point. An inking wheel revolves freely on each of the helices. The letters appear transversely upon the strip at right angles to the ordinary Morse characters, the paper being raised to the writing helix by the armature of the electro-magnet over which it passes. This transverse disposition of the letters presents a double advantage; it avoids confusion between consecutive letters, and reduces considerably the length of the paper band used for each despatch.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Multiple transmission in this case depends upon identical revolutions, in the same time, of certain portions of the apparatus at distant stations. This is effected by the aid of a conical pendulum and a regulating system, by which a correcting current is transmitted every second; and it is arranged that the line should be put to earth at both extremities after each emission of the current.

Electrical Instruments.—The Thomson galvanometer, Fig. 61, is made in a variety of forms. The form most in use consists of a base of a round plate of ebonite, provided with three levelling screws; two spirit levels, at right angles, are fixed on the top of this plate, so that the whole instrument can be accurately levelled. Sometimes one circular level only is provided, but the double level is much the best arrangement. From the base rise two brass columns, and between them a brass plate is fixed, rounded off at the top and bottom. Against the plate are fixed the coils, the ends of which are shown by dotted circles. The brass plate has shallow countersinks in its surface for the faces of the coils to fit into, so that they can be put in their correct places without trouble or danger of shifting. Round brass plates press against the outer surfaces of the coils by means of screws, and keep them firmly in place. There are two round holes in the brass plate coinciding with the centre holes in the coils. The coils, Fig. 62, are four in number, and are wound on bobbins of brass, the wire being coiled thicker towards the cheek of the bobbin which bears against the brass plate. This curving of the section of the coil is in accordance with the law of W. Thomson, to obtain a maximum effect from a minimum quantity of wire. The edges of the coils are covered with shellac, to protect the wire from mechanical injury. Within the holes in the brass plate are placed two magnets *n s* and *s n*, formed of watch spring highly magnetized, connected by aluminium wire, to form an astatic pair of needles. A groove is cut in the brass plate between the upper and lower hole, for the connecting aluminium wire to hang freely in. In front of the top needle is fixed the mirror. The suspension fibre is attached at its upper end to a small stud which can be raised or lowered as required. When pressed down as far as it will go, the needles rest upon the coils, and the tension is taken off the fibre; the instrument can then be moved about without danger of breaking the fibre. One end of each coil is connected with one of the four binding screws in front of the base of the instrument, the other ends being connected to one another through the binding screws. The whole four coils are in the circuit of the two outer binding screws, so that they all act upon the magnetic needles. By connecting the first binding screw on the base with the third, and the second with the fourth, the coils will be coupled up so as to reduce the resistance to one-fourth of the total resistance of all the coils together. Over the coils a glass shade is placed, from the middle of the top of which a brass rod rises. A short piece of brass tube slides over this rod with a weak steel magnet, slightly curved, fixed at right angles to it. This magnet can be slid up and down the rod, or twisted round for adjustment of the mirror. For

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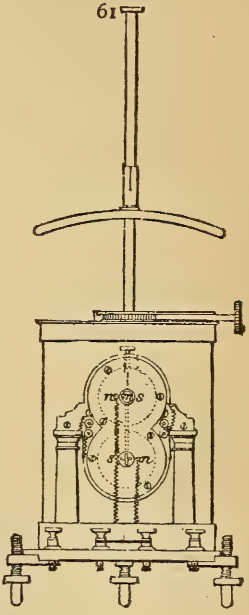

fine adjustments a tangent screw is provided, which turns the brass rod round, and with it the magnet.

The mirror is sometimes made of a plano-convex lens, to obtain a sharp image of the spot of light on the scale. The width of this spot of light can be regulated, by means of a brass slider fixed over the hole in the screen through which the beam emerges from the lamp. A much better arrangement than the spot of light is to make the hole through which the light emerges round, with a piece of fine platinum wire stretched vertically across its diameter. A lens is placed a little distance in front of this hole, between the scale and the galvanometer, so that a round spot of light with a thin black line across it is reflected on the scale. This enables readings to be made with great ease, as the figures on the scale can be more distinctly seen. The mirror in this arrangement may be a plane one. When the spot of light only is used, it is necessary to partly illuminate the scale with a single lamp.

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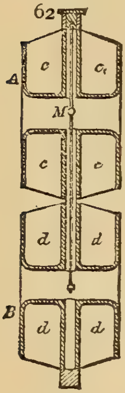

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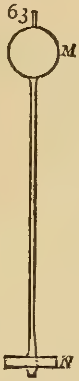

Fig. 62 is a sectional view of the coils, showing the mirror M and the lower needle N, removed in Fig. 63. When these instruments are used for receiving communications through cables, they are placed in a box or curtained compartment, and the receiver calls off each word to a clerk, in attendance, who writes it down. The spot of light wanders over the scale, following every change of current, but the operators, by practice, acquire the necessary skill to interpret the apparently irregular motions. One dot will cause the light to almost cross the scale, the second moves it a little further, the third or fourth causes hardly a perceptible motion, but the receiver knows by experience that these four very different effects each indicate a series of dots, all sent by the transmitting operator in precisely the same manner.

Thomson's marine galvanometer is a reflecting galvanometer, constructed in such a manner that the oscillations of the vessel cannot change the relative position of the small mirror and the scale, when used on board cable ships, and for other similar purposes. The magnet is attached by means of cocoon fibres, at the top as well as at the bottom, to small wooden frames, which support the convolutions of wire. The cocoon fibres pass accurately through the joint centre of gravity, both of the magnetic bar and the mirror, so that, when the wire of the coil is turned, the latter remains unaltered in its relative position to the convolutions. The magnet thus retains, in any position of the instrument, the same position in relation to the scale attached to it on the same table.

This instrument has the influence of terrestrial magnetism upon the magnet destroyed. This is attained by enclosing the multiplicator wire with magnet mirror and lens in a case of soft iron, and by putting in the box a moderately strong steel magnet. The magnetic action of these poles upon the magnet needle being stronger than the attractive power of the earth, the latter is neutralized, and the suspended needle is maintained in a position of rest under the changes of the situation of the instrument.

To avoid the disturbing movements of the spot of light upon the screen, caused by the shaking and flickering of the flame, the lamp is inclosed in a cylindrical case, in which, on the side turned towards the mirror, is a small slit. When the galvanometer needle is at rest, the spot of light appears exactly upon the middle of the screen.

Electrometers are made in different forms, some of which are historical. They all depend, for measurement of the intensity of the electrical potential, upon the repulsion or attraction of a light body by a fixed body, both being electrified. Practically only one electrometer is in use, and it is known as the reflecting quadrant electrometer invented by W. Thomson. This instrument consists of a metallic box, cut into four quarters or quadrants, which are slightly separated, and well insulated from each other. Within the box is suspended a flat needle, the extremities of which are broader than the middle. This needle has a bifilar suspension and communicates electrically with a Leyden jar. The Leyden jar is maintained at a constant electrical potential, by means of a small charging apparatus attached to the instrument, and by placing the jar in an atmosphere deprived of moisture, by contact with highly concentrated sulphuric acid. Each two diagonally opposite corners of the box, within which the needle swings, are connected electrically, so that the needle, when each set of quadrants is electrified to the same potential, has no tendency to deflect from the position given to it by the bifilar suspension. When one set of the quadrants is electrified to a lower or a higher potential than the other, or when each set is oppositely electrified, the needle will be so deflected, as to be attracted by the lower or opposite potential or repelled by the higher or similar potential. The deflection is proportional to the difference of potentials, when indicated by a beam of light reflected from a mirror on the axis, of the needle, to a scale, as in the reflecting galvanometer.

Electrometer observations are attended with considerable difficulty, consequent upon the liability of the state of the atmosphere to influence the instrument, and because accidentally touching certain parts in connection with the Leyden jar may cause its discharge, when all previous observations must be repeated. The instrument is besides not portable, and cannot, like the galvanometer, be easily set up; it is, therefore, very usual in practice, to substitute a combination of condenser and galvanometer for the electrometer.

In the Thomson quadrant electrometer an inverted bell glass is externally coated with tin-foil, which is put in communication with the earth. In the interior of the jar is concentrated sulphuric acid, into which dips a platinum wire attached to the needle, suspended in the quadrantal box. The quadrants are supported from an ebonite disc, and are adjustable with regard to each other, so that the needle may be brought to the zero of the scale. Measurements with the electrometer are chiefly made in the factory with short lengths of india-rubber or Hooper's cores. Beyond this application to the measurement of insulation by loss of charge, the instrument does not meet with much favor in the testing room.

Condensers are usually prepared with sheets of tin-foil separated by sheets of mica, or of paraffined paper. Mica is used for small, and paraffined paper for large condensers. Mica condensers are more durable, but the capacity varies with sudden alteration of temperature, consequent upon the separation or approximation of the tin-foil sheets.

In the construction of the condenser, there is first laid upon a metal surface plate, a sheet of tin-foil, the commencement of the earth armature. Upon this is laid a sheet of insulating material, mica, or paraffined paper, of much larger area than the sheet of tin-foil, but having one of its corners removed so as to expose the tin-foil; upon this sheet of insulating material is laid another sheet of tin-foil, which is the commencement of the line armature. This is followed by another sheet of paper, so cut at the opposite corner to the first sheet, as to similarly leave a portion of the tin-foil exposed. A sheet of tin-foil is now superposed so that it is in contact at the cut corner of the paper with the sheet first laid down, and forms the second sheet of the earth armature. By continuing the operation the construction of the condenser is completed, when as many sheets have been laid down as are necessary to give the required capacity. About 10 sq. ft. of tin-foil surface, or 5 sq. ft. in each armature, is necessary for a condenser of one microfarad capacity; but the capacity depends upon the proximity of the plates, and may be slightly greater by subjecting the condenser to pressure during manufacture. When completed the condenser is usually placed in a warm atmosphere upon a heated surface-plate, and is loaded with about 8 cwt. When the condenser is sufficiently warmed through, the source of heat is removed, and the sheets are allowed to cool in their compressed condition. The condenser is finally surrounded with solid paraffin in a box.

The paraffin to be used in the making of condensers should not be heated in a brass or copper vessel, as if it absorbs verdigris it becomes conducting. Where condensers are to be used in very hot climates 2, or 3 per cent. of Carnauba wax is added with advantage to the paraffin. For the manufacture of paper condensers, paper containing mineral substances is useless, and the best variety appears to be that known as cream-wove bank post from linen rags. Mica for use in condensers must be clear and free from fracture; black mica is not suitable for the purpose. Condensers should always be left with their armatures connected electrically, so that they may be completely discharged when required for use.

The siphon recorder invented by W. Thomson is so arranged as to actually delineate on paper the apparently irregular movements of the galvanometer needle. A fine glass siphon tube conducts the ink from a reservoir to a strip of paper, which is drawn past the point of the tube with a uniform motion. The point moves to the right or left of the zero line, through distances proportional at each instant to the strength of the current, and thus the signals are drawn on the paper in curves.

Fig. 64 shows the form of siphon recorder in use at the Duxbury Station of the French Atlantic cable. The apparatus consists of a very light rectangular coil *b b* of exceedingly fine insulated wire, suspended between the poles of a large and powerful electro-magnet N S, which is charged by a local battery of large size. Within the coil is a stationary soft-iron core *a*, which is powerfully magnetized by induction from the poles N S. The coil *b b* swings upon a vertical axis, consisting of a fine wire *f f* the tension of which is adjustable at *h*. The received current passes through the suspended coil, the suspension wire *f f* serving as the conductor; the coil is impelled across the magnetic field in one direction or the other, according to the polarity and strength of the current passing through it. The magnetic field in this arrangement is very intense and very uniform, which makes the apparatus sensitive to the weakest currents. The siphon *n* consists of a fine glass tube turning upon a vertical axis *l*; the shorter end is immersed in the ink reservoir *m*, and the longer end rests upon the paper strip *o o*. The siphon *n* is pulled backward and forward, in one direction, by the thread *k*, which is attached to the swinging coil *b b*, and in the other, by means of a retracting spring attached to an arm on the axis *l*, and controlled by an adjusting spindle. The paper is caused to move at a uniform rate by means of gearing driven by a small electro-motor. Fig. 65 is a fac-simile of the writing of the siphon recorder at a speed of eighteen to twenty words a minute, through a cable of about 800 miles in length. The upward waves represent dots, and the downward waves dashes. In working very long cables, the action of the current upon the swinging coils is very feeble, and the friction of the siphon against the paper strip, if allowed to come in actual contact with it, would interfere with the freedom of its movements. In such cases the point of the siphon does not actually

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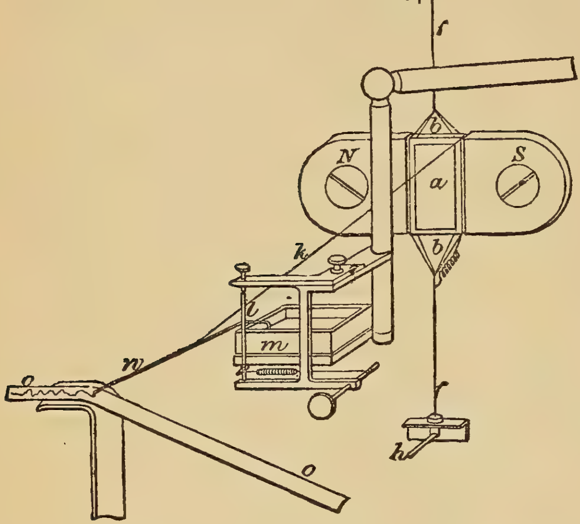

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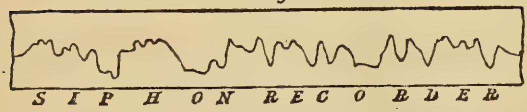

touch the paper; the ink and the paper are oppositely electrified, by means of an inductive machine driven by the electro-motor that moves the paper. The electrical attraction causes the ink to be ejected from the siphon upon the paper in a succession of fine dots.

In introducing the relay into diagrams of apparatus, it is often represented in the conventional manner shown in Fig. 66, in which *b b'* is the armature lever, *d* the insulated or resting contact, and *d'* the closing or working contact. L L represents the main circuit, and the dotted lines O the local circuit.

Various other forms of relays have been introduced. A relay designed by Siemens and Halske, with a movable core, but without an armature, Fig. 67, has been much used. The helices *m m'* are electrically connected in the usual manner, A and B being the main binding screws. One of the cores *x* is stationary, the other one *y* turns upon screw points *r*; both of these cores are provided with pole pieces, which face each other. The contact arm *z* is rigidly attached to the movable core *y*, and serves to open and close the local circuit at the contact screws *k k'*, the former being insulated. The adjusting screw *g* regulates the tension of the relay spring *f*. C and D are the local connections.

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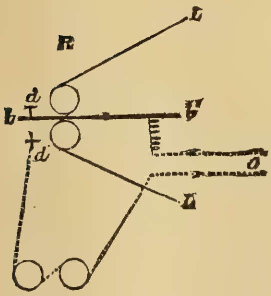

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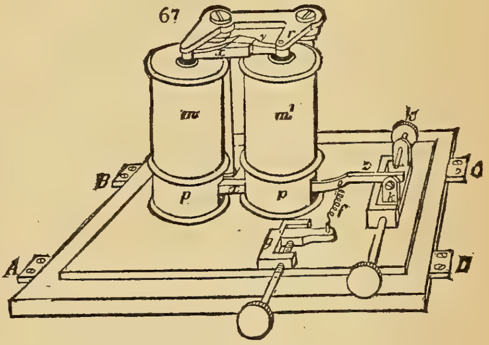

The form, Fig. 68, is known as the American relay, and is the simplest in principle, being an armature *b* held back by a spring *f*, and attracted by the magnetism generated by the passage of the currents in the coils M, of the electro-magnet; *d* is the working, and *c* the rest stop; *g* is an adjusting screw; L' and L'' are the line; and *l'* and *l''* the local connections.

Siemens' polarized relay is in general use, and is regarded as an improvement on the ordinary Morse relay, particularly as it does not require any adjustable spring as a retractile force. Fig. 69 is a plan of this instrument, and Fig. 70 the vertical section through the centre. The relay consists of a steel magnet N S, bent to a right angle, on whose leg N the soft iron cores n n', and the wire coils or helices m m,′ of an electro-magnet are fixed. At the extreme end of the other leg S is a small soft-iron bar c c', which operates as a relay lever and armature, turning horizontally on its pivot B. The motion of this armature is limited by the metallic screw D on the one side, and by the agate stud D′ on the other. On the leg of this magnet the iron coils n n' are attached, upon which the coils m m' are wound. The south pole S polarizes the tongue c c'.

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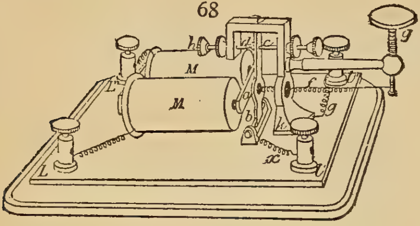

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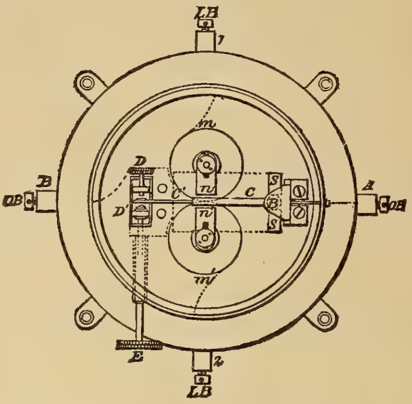

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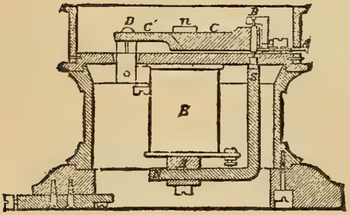

Soft iron, when placed in contact with the pole of a magnet, becomes itself magnetized, and takes the same polarity as the pole with which it is connected, so that the upper ends n n' of the iron core, standing on the north pole n, form permanent north poles, and for the same reason the extreme end c' of the armature c c', which at S stands on a south pole, is permanently a south pole. Therefore, the armature will be attracted equally by north pole n and n', but if it be brought nearer to one than the other it will be held there. If the attraction between n' and c' predominates, the armature lever will lie against the point D, and if the attraction is greater between n' and c' it will rest on the agate point D′. It is evident that the latter position, where the local battery, which is put in between D and B, is open, corresponds with the position of rest of the ordinary relay.

When the key is closed at the remote station, and a line current is sent through the coils *m m'*, one of the poles, *n n'*, becomes oppositely polarized. Suppose that this current causes at *n*, a north pole, and at *n'*, a south pole, then the north magnetism already at *n* is increased, but destroyed at *n'*.

As the south magnetism at *c* is, however, unchanged, the attraction of *n* towards *c'* is predominant, and the tongue of the lever, *c c'*, strikes against the contact screw D, and closes the local circuit.

When the line current ceases the lever still remains in contact with screw D, as although the electro-magnetism from *m m'* disappears, the attraction between *c* and *n* continues predominant, on account of *c'* being nearer to *n*.

The return of the armature, *c c'*, to its former position can only be effected by a reverse current, which is produced at the remote station by a pole-changing key, the south magnetism being induced at *m*, and north magnetism at *m'*, by which the north magnetism already to be found at *n* is decreased and strengthened at *n'*, consequently the former attraction between *n* and *c'* is destroyed, and the attraction between *n'* and *c'* predominates. The tongue *c c'* thus again strikes against the insulating point D' and interrupts the local circuit, whose poles are connected with A and B.

No adjustment of the armature lever is required after it has been properly placed by means of the regulating screw E, no matter which pole of the battery is to line, and thus the use of a spring as a retractile force is entirely dispensed with.

The polarized relay can be very advantageously used for ordinary battery currents of one direction. For this purpose it is only required that the movable pole pieces *n n'*, shall be placed at different distances from the polarized tongues *c c'*. The piece, *n'*, which corresponds to the rest or D' side, must be placed nearer to the tongue *c c'* than the piece *n*. In this case, as long as no current passes through *m m'*, the attraction to the north pole, *n'*, of the south polarized tongue *c'* increases; consequently the armature *c'* is constantly attracted by *n'*, and remains against the insulated point D' interrupting the local circuit. When, however, a line current arrives of such a polarity as to form at *m* a north pole, and at *m'* a south pole, then the north magnetism already present at *n* is increased, and the south magnetism present at *n'* destroyed or replaced by south magnetism, so that the attraction of *n* and *c′* predominates, and accordingly the tongue *c c′* is drawn over to the opposite side, and closes the local circuit at D. With the breaking of the line current the magnetism at *m* and *m′* again ceases, but the north magnetism at *n n′*, caused by the steel magnet N S, remains, and consequently the tongue at *n* should remain in the same position; but as the space for motion between D and D′ is very small, only a slight change is made in the distance of the tongue from *n* and *n′*, on account of its movement towards *n*, and it has thus, as before, on account of its position, more attraction for *n′* than for *n*. As *c′* stands nearer to *n′* than to *n*, the attraction of *n′* predominates, and the tongue is pulled back, interrupting the local circuit until another line current closes it.

The polarized relay is exceedingly sensitive on account of the absence of the retracting spring, the force of which the electro-magnet is not obliged to overcome, and also because the action of the poles *n* and *n′*, on the armature *c c′* is a double one, attracting and repelling at the same time. No adjustment is required to meet the varying strengths of the line current. To adjust the polarized relay, the pole pieces *n* and *n′* are placed at a convenient distance apart, and the screw B turned until the tongue is brought as nearly as possible in the centre between the poles, so as to have equal room for adjustment on each side. The set screw, D, is adjusted so that the motion of the tongue or armature lever, shall be about one-twentieth of an inch between the insulated stud D and the contact point. The adjusting screw E, is then turned, so that the armature, when no current is flowing, shall be slightly attracted by the pole *n′*, bringing the tongue into contact with the agate point D′. If, after the instrument is so adjusted, the armature lever remains permanently in contact with the circuit closing point D, when the distant station is sending, the screw E is turned to the right, so as to lessen the attraction of *n* and increase that of *n′*. If this produces no effect, either *n* is placed farther from, or *n′* nearer to the tongue, until the desired result is obtained.

Allen and Brown's relay, Fig. 71, consists of an electro-magnet A, of proper form and dimensions, suspended between permanent magnets, and free to move, when excited, to right or left, as far as the compensating springs which are attached to one end of its core will allow. These springs will only permit the electro-magnet to move to a point where the potential of the current and the tension of the springs balance each other; and the electro-magnet will truthfully follow the pulsations of the received current in a natural manner.

A contact arm is loosely pivoted on the top of this moving coil, and is termed a jockey armature, which, being light, and favorably placed, opposes only the friction caused by its weight to the free movement of the coil. A local circuit made through this jockey would be closed the moment the coil moved, and would remain closed as long as it continued to move in the same direction, but immediately a fall of potential took place, and the coil, through the action of the springs receded, however slightly, the local circuit would be broken.

It is possible, with this relay, to obtain arbitrary characters, such as the Morse, or a rise or fall of potential, without bringing the cable current to zero. The weight of the "jockey" gives sufficient friction for contact purposes, the spiral spring of the centre pivot being seldom used. An increase of friction means so much more opposition to the free movement of the coil, and is detrimental proportionately. The local contact points, on each side of the jockey, may be either or both used, if a reverse current in the local circuit be desirable.

The local contact points must be adjusted so closely, that no motion of the jockey is visible; sufficient only to make or break the local circuit being necessary. The compensating springs should be adjusted rather stiffly so as to ensure the greatest amount of elasticity.

The electro-magnet of whatever local instrument is used in direct communication with the cable relay, may be shunted with a condenser of, say, 10 microfarads, to avoid the spark at the point of contact on the jockey. The success of this relay is due to the fact that it affords what is termed a moving zero. Relays generally in use have fixed or dead zeros.

Instruments cannot be worked with reasonable speed through cables over 300 miles which do not afford this quality of a moving zero, and the success of the Thomson mirror and recorder, and the Allen and Brown relay, is due to their containing this element. On cables of 300 and 400 miles this jockey armature can be attached advantageously to any existing instrument, such as a Siemens or other relay, Fig. 72, and the speed increased.

Wheatstone's automatic apparatus, introduced in 1858, is considered by electricians to be the most perfect form of automatic telegraph brought into practical use. The apparatus includes a perforated strip passed through a transmitter, with a polarized receiving instrument. In earlier automatic telegraphs, contact was made directly through the perforation of the paper, by passing the paper between a metallic brush and a wheel; but in this construction dust or fibres of the paper interfere with the contacts, and the edges of the perforation act upon the brush, to prevent it from touching the metal wheel, for a considerable portion of the space allowed for contact. Attempts were made to obtain better results by lengthening the perforations of the paper, and by running the machine faster. In Wheatstone's transmitter the contacts are made between levers and studs, the paper being used only to regulate the movements of this contact piece. This plan gives much more uniform and certain contact than can be obtained between the brush or spring, and the revolving wheel, besides affording great facility for transmitting the compensating currents required at high speeds. The principle in Wheatstone's apparatus is that the polarized arm of the electro-magnet, which causes the marking disc to touch the paper, shall not have a tendency to leave the paper when the marking current ceases, but to remain always in the position where left by the last current. The transmitter is arranged to send a series of reversals, or limited positive and negative currents, at regular intervals, and the perfora-

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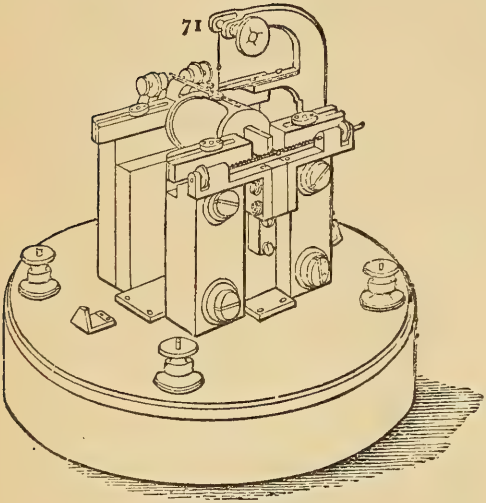

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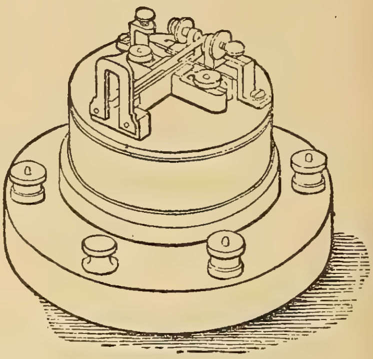
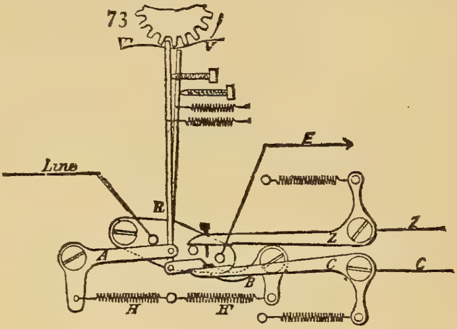


ted strip controls these currents of either sign in their passage to line. An ebonite rocking beam R, Fig. 73, actuated by clockwork, carries three pins; that on the left being connected to line, and that on the right to earth. The centre pin is insulated, and can connect the curved lever B with one or other of the battery levers Z C, controlled by the position of the rocking beam. Beneath the beam are two levers, A B, pivoted independently, but in electrical connection through the spiral springs H H′, and through the frame of the instrument. These levers carry two vertical needles, one of which, V, regulates the marking, the other, V′, the spacing current. The levers follow the movements of the rocking beam, and remain in contact with the pins in this beam so long as the upward movement is unchecked; the needles attached to this lever rise alternately until they touch the paper ribbon. If there is a hole in the ribbon, the needle passes through, and the contact remains unbroken; if the paper is unbroken the motion of the needle and that of the lever is stopped, and the pin in the rocking beam continues to rise, and the circuit is interrupted. Fig. 73 is of the apparatus in a position for sending a negative current; the lower lever, C, touches the right-hand pin on the rocking beam, putting the copper pole to earth; the upper lever, Z, rests on the centre pin of the beam, and is in connection with the line over the lever B, the spiral springs, H H′, in the frame of the instrument, the lever A, and the left-hand pin. When the circuit is broken, the rising of the lever A is prevented by the paper, the vertical needle, V′, attached to it not meeting with a hole in the strip. The contact between the lever A and the left-hand pin is broken, and there is no current passing to line.



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From well-known inductive effects on the line, no more than 70 words a minute are attainable by automatic telegraphs, based on the Bain's principle of brush contact. By the use of alternating currents speed is increased, but is still considerably lower than the maximum attainable on a given line. The succession of currents of equal duration of opposite signs, at equal intervals, will give perfectly distinct dots, at very much higher speed than the dots of alphabets can be produced. Wheatstone's transmitter produces the Morse signs by currents of equal duration, that is by a succession of dots, but as the intervals between the characters are necessarily unequal, the alphabet is more slowly produced than a series of equidistant dots. The speed of a succession of alphabet letters depends also on the distance between the letters; the greater the distance the slower the speed, because an additional element of variation in the electrical condition of the wire and the magnetism of the receiver is introduced. Speed is generally limited more by defects in the formation of the letters than by the complete loss of dots or blurring of marks, and the defects are greatest where there is the most irregularity in the intervals between currents, as, for instance, in the letters F and R in the Morse code, the Morse signals for which are — — —— —, — —— —.

It is necessary, therefore, to employ a system of compensating currents, to maintain uniformity in the condition of the line wire. This was effected at first by bridging over the break in the circuit, which occurs when the pin is stopped by the paper, by a weak current passed through resistance coils, the strength of the current being regulated by varying the resistance.

Fig. 74 is of a piece of the perforated strip. The perforations which regulate the contact-making portions of the transmitting apparatus are represented by the larger holes, while the centre row of holes serves for guiding the paper through the transmitter. The slip is perforated for transmitting the letter R; the upper row of holes is that which allows the positive or marking current to be sent, when the vertical pin, V, of the transmitter, passes through one of them; the lower row of holes allows the negative current to be sent when the vertical pin, V′, passes. Fig. 75 is of the letter R as received at high speed, on a line where the original system of intermittent currents is employed. In the case of the dot before the dash, the positive, then the negative, and finally a second positive, giving two positive and one negative currents, are sent to form the dot and commence the dash, so that twice as much positive as negative electricity is sent into the line, and the dot is consequently much elongated, and has a tendency to blur into the dash. In the case in which the

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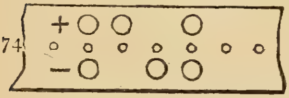

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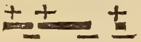

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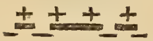

dot follows the dash, the effect is reversed, the space increased, and the dot shortened or lost. Fig. 76 is of the letter R as received when compensating currents are used, and is perfect in form. The compensating currents are represented by the smaller signs. Before the commencement of the dot the line is charged negatively, instead of being clear, as in the original system, and prevents the elongation of the dot before the dash. In the case of the dot following the dash, the positive compensating current is sent before the terminating current for the dash, so that the line is not too highly charged with negative current, as would be the case were no compensating current used.

This instrument has given some very instructive results in the working of compound lines, part of which are of cable and part of overhead wires. It has been found that in circuits partly of overground wires, and partly of buried or submarine wires, that the position of the buried wire will affect the speed at which the two stations can receive from each other. If the buried portion is placed symmetrically with respect to the two stations, as when the land lines at each end of the cable are of equal length and resistance, the two stations will be able to receive equally well, but if the land lines on one side are much longer than the other, the rate at which the station situated at the end of the shorter line will be able to receive, will be less than that at which the station situated at the end of the longer line can receive from the other. This difference of speed is sometimes very considerable, and the difference is greater as the length and resistance of the land lines on each side of the cable are more unequal. The London and Amsterdam circuit consists of a suspended wire of 130 miles, then a cable of 120 miles connected to a suspended wire of 20 miles. Amsterdam can signal to London at a rate higher than signals can be sent in the opposite direction, as nine to six. The rate of signalling to Amsterdam is increased by decreasing the resistance of the batteries, and by the insertion of a high resistance, as much as 5000 ohms, at Amsterdam, in the receiving circuit, to delay the discharge of the cable. In the case of the London-Dublin circuit, where the land lines are 266 and 10 miles respectively, and the cable 66, the addition of resistance at Dublin in the receiving circuit has no appreciable effect, because the length of land line on the English side is too great to permit the cable to be sufficiently charged. Here the speeds are 40 and 80 respectively. With Wheatstone's automatic telegraph the speed between London and Manchester or Liverpool is 120 words a minute, in some cases as many as four intermediate stations are introduced in the circuits devoted to press work, in which 1000 words are sent simultaneously to each station in twenty minutes, with regularity.

The arrangement of circuit, Fig. 77, is that in use in America, for automatic telegraphing on long circuits. A is the transmitting, and B the receiving station. At the transmitting station two equal batteries, E and E_1, are placed in the main circuit, with their like poles towards each other, and normally produce no effect on the line. When, however, the battery E_1 is shunted by the closing at the transmitter of the short circuit 1, 2, 3, 4, the current of the battery E passes over the line to the receiving station. When the circuit of the transmitter is broken, the flow to line ceases; and the return or static charge is neutralized by the magneto-electric discharge of M, which consists of an electro-magnet with its armature permanently in contact with the poles. The recording instrument at the receiving station is shunted with a series of helices M′, arranged on iron cores, the former being continuous, and the latter divided into sections, which may be connected or disconnected by the insertion or withdrawal of iron contact plugs, so as to increase or diminish the length of the core under the single inductive action. In this way the duration of the discharge from the helices may be adjusted to correspond with that from the line. The discharge from the helices M^1 will be in the reverse direction to the primary current, and will neutralize that portion of the inductive discharge tending to pass through the receiving instrument at B. This effect

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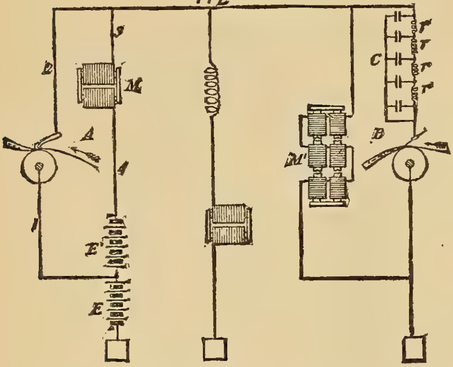

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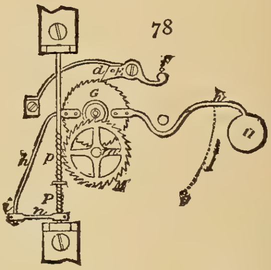

is increased by the adjustable condensers C, which are arranged in connection with the resistances *r*, so that the time of the discharge may be graduated to produce the best effect. In very long circuits it has been found advantageous to connect the main line with the earth, at one or more intermediate stations, including in this derived circuit an electro-magnetic coil of high resistance. In circuits of moderate length the battery E^1 is dispensed with, and an adjustable rheostat is placed in the wire 3, so that the current passing through M may be regulated to produce a proper effect.

With the usual Morse receiver, when the telegraphist hears the signal for commencing a correspondence, he liberates the clockwork and draws the paper strip forward, but in case of absence or inattention the message cannot be received. To make the recording apparatus self-starting, several devices have been proposed. Sortais employs on the last horizontal axis of the clockwork a wheel M, Fig. 78, which gears into an endless screw *p*, on a vertical axis. A thin spiral spring, P, is fixed, at its upper end, to this shaft, and at its lower end to a horizontal arm *n*, which turns upon the shaft. A single projecting tooth, *m*, on the axis of the wheel M, turns a ratchet wheel G, upon an axis fixed in the side of the apparatus. This wheel carries a bent wire and a counterpoise, *i*, at the extremity of an arm *h*, tending always to turn the ratchet and lift the bent wire away from the arm *n*. This is prevented by a click E, held down upon the wheel by a spring. On the click is a pin *d*, which passes through a hole in the side of the apparatus, and is so placed that the writing lever, when deflected half-way between its highest and lowest points, will strike against the end. The force with which the wheel tends to turn the endless screw shaft is balanced by the tension of the spiral spring P. When the current is received, the writing lever is deflected, strikes the pin *d*, raises the click, and allows the ratchet wheel to turn round with its counterpoise, releasing the catch, *n*, from the wire *i*. As long as currents are being sent the click is continually being struck out of gear. When the currents cease, the click keeps every tooth of the ratchet, which is pushed forward by the tooth *m*, until the wire again blocks the way, and prevents the rotation of the catch. The use of the spring P is to allow the tooth *m* to clear the ratchet wheel, so as not to prevent its release.

The double current key which is used for long circuits in England, India, and other countries, is so arranged as to completely reverse the battery after each signal; that is, instead of the spaces between the signals being formed by merely breaking the circuit, a reverse current is sent into the line, so that the battery when working is always connected to the line in one direction or the other. Fig. 79 shows the arrangement of the double current key usually employed in England. The line wire is attached to binding post 3; the earth wire and one side of a polarized relay to 7, the other side of the relay being connected to 4. The positive pole of the battery is connected with the binding post C, and the negative pole with Z. L L' are two levers, insulated from each other, and moving upon the same fulcrum by pressing upon the knob attached to L'. $s s'''$ are two insulated springs connected with Z, and s' s'' are two similar springs connected with C. When the knob of the key is depressed, a positive current is transmitted through the spring s' along the lever L' to button o, thence by switch S' and screw post 3 to line; and a negative current is sent through spring s along the lever L to button g, thence by switch S'' and screw post 7 to earth and one side of the relay, the other side of the relay being connected with screw post 4 and button p, which is disconnected when the switch S is turned to send.

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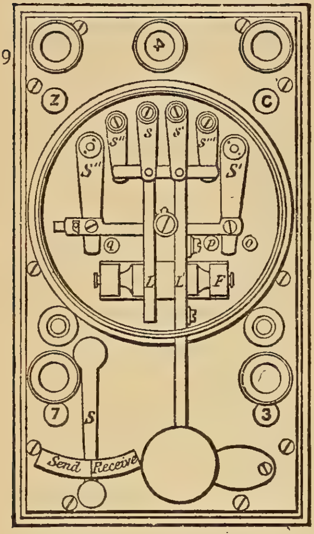

When the knob of the key is not depressed the levers L and L' rest upon springs s'' and s'''. A negative current passes from spring s''' to lever L', and thence to button o and switch S' to screw post 3 to line, and a positive current passes from spring s'' to lever L, button q, switch S'', and screw post 7 to earth. Thus the line is always charged either with a positive or negative current, whether the key is raised or depressed. When the switch is turned to receive, the battery is disconnected; the current from the line enters at screw post 3, passes to switch S', button p, screw post 4, and thence to the relay and earth. When the switch is turned to send, the line wire is disconnected from the receiving apparatus, and the receiving operator cannot stop the sender until the switch is turned from send to receive. Sometimes a tell-tale galvanometer is used, wound with two separate wires, one of them in the sending and the other in the receiving circuit. In sending, the receiving coil is switched out of circuit, but the sending is affected by both outgoing and incoming signals, and the breaks of the receiving station are then readily felt, and the sender's attention attracted.

One of the most ingenious and largely used of the type-printing telegraphs is that of David Hughes. In this the synchronous movements of type wheels at two or more stations, are combined with the power to press a strip of paper at each station, simultaneously, against the types on the corresponding parts of the wheels, by the action of a single electric impulse.

A clockwork at each station turns, with a continuous and uniform motion, an axle, at the extremity of which the type wheel is supported. The synchronism is attained by the aid of a vibrating spring and anchor escapement. The rotation of the type wheel is transmitted to a vertical arbor, furnished at its lower extremity with a horizontal arm travelling over a circular disc, in which is arranged a series of contact pins, in number corresponding with the types. Each pin therefore represents a letter, and is raised when it is wished to telegraph this letter along the line. The horizontal arm, which travels round the disc with a motion uniform with that of the type wheel, comes in contact with the pin just at the moment when the corresponding type is at the lowest point, and closes an electric circuit, by which the paper is lifted up against the type wheel, and the letter printed.

The key-board used to elevate the contact pins, Fig. 80, consists of twenty-eight keys, alternately white and black, marked with the twenty-six letters of the alphabet, a full stop, and a blank, corresponding to an empty space in the type wheel. Below each of the keys is a movable lever, whose fulcrum is at K″, and which terminates at the bottom of one of the contact pins K K, arranged in a circle in the metal box A, in the top and bottom of which are holes for the ends to protrude, the upper holes being long, to allow of a radial motion. Each pin is held down by the pressure of a small spring, but may be elevated by pressing down the corresponding key of the piano-board.

Fig. 81 is a vertical section of the printing instrument and key-board. The section shows a white key, hinged at K″, connected to its lever K′, a contact pin *k*, on the right, and also to a black key, whose lever reaches to a contact pin on the left of the box A. The contact pins are provided with shoulders to limit their movements in each direction.

The horizontal arm, which travels over the circle of contact points, is attached to the bottom of the vertical arbor Q, to which motion is imparted by the bevelled wheel G_2, on the shaft G. It is made up of three principal parts, the arm *r*, jointed at *a;* the resting piece, or earth contact *r′*; and the shovel *r″*. The vertical shaft Q is of brass, and is divided electrically into two parts by an insulating ring of ivory, *q*. The lower part is supported by the central pedestal, which is insulated from the box A, by a non-conducting ring.

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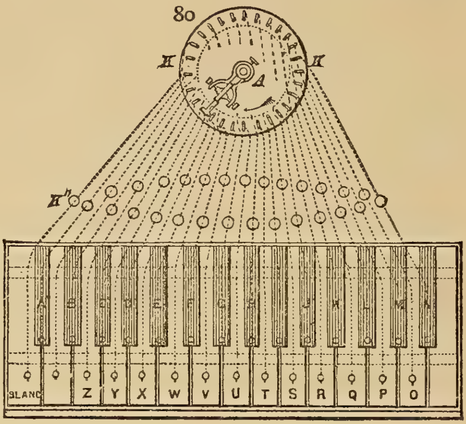

The continuation of the jointed arm *r*, which is held by the portion of the shaft above the insulating ring *q*, is pressed down by a spring, which keeps a small screw in the middle of the continuation in metallic contact with the second piece *r′*, supported by the portion of the shaft below the ring. The shovel *r″*, is of steel.

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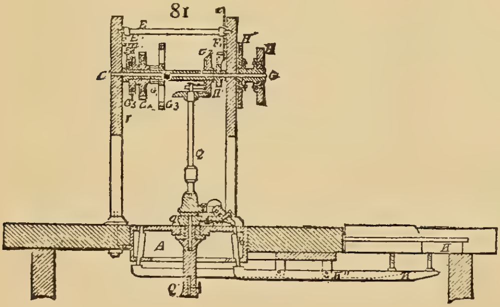
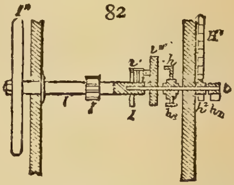


When a key is depressed, the corresponding contact pin is elevated, and if the arbor Q is in motion, the extremity of the arm *r* mounts upon the elevated pin, by which contact between *r* and *r′* is interrupted, and that of *r* with *k* established. The arm *r* having made contact, the shovel *r″*, which immediately follows it, pushes the pin *k* in its slot outside the circumference swept over by *r*; so that if the latter makes another revolution whilst the finger is kept down upon the key, no second contact is made, and the same letter is not repeated. The operator feels a vibration of the key as the shovel passes by the pin, and is thus made aware that the letter has been printed.

The type wheel H contains on its circumference, in twenty-eight equal spaces, twenty-six letters of the alphabet, a dot, and a blank space; it is fixed to the extremity of the axis CC′, which is put in motion by means of the hollow axis, G, enveloping it in the greater part of its length. The connection between CC′ and G is made by the mediation of a fine ratchet wheel G_5, attached to the axis G, the click *m* being on the axis CC′. On the latter are supported, besides the type wheel and click, a correcter H′, or wheel with long narrow teeth, equal in number to the types, serving to establish precision between the movements of the horizontal arm *r*, and the type wheel. On the same axis is a wheel H_1, having a notch at one part of its circumference, for stopping the type wheel when the blank space is opposite the printing press, in case it should spring forward. The hollow axis G is turned by a clockwork moved by a weight, a wheel of which engages with the pinion G_1, and supports, besides the wheels G_5, G_2, the escape wheel G_4, and a tooth-wheel G_3, which locks into the pinion I_1 of the printing shaft I, shown in section in Fig. 82.

The printing shaft turns seven times as fast as the type wheel, and carries a fly-wheel I″ at one extremity, in order to overcome the inertia of a small shaft, whose duty is to lift the paper up to the type wheel at the other extremity. The printing shaft I, and its continuation *i*, are locked together by means of a ratchet wheel I, and click *i*″. At the end of the continuation shaft *i*, is a cam *h*, for lifting the press and the paper against the type wheel.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In the printing press underneath the type wheel is a small cylinder, over which the paper is led, its axis being in the middle of a bent lever; attached to it is a ratchet wheel, in the teeth of which catches a click affixed to a movable piece, terminating in a rectangular arm, which is forced upwards by a spring attached to the frame of the apparatus, but is stopped against the axis. When this makes one revolution, the cam lifts the arm of the lever, together with the cylinder and paper strip, up to the lowest tooth of the type wheel, by which the paper strip is impressed with the print of the type, kept inked by an inking roller. The cam being very sharp, the movements of ascent and descent are proportionately rapid, and the paper touches the type during only an infinitely short space of time. The axis continuing to turn, the cam meets the arm, and depresses it, causing the click to draw round the cylinder and advance the paper a certain distance.

By the side of the ratchet wheel the printing shaft carries an escapement *h h'*, arrested by a continuation of the lever moving with the armature of the electro-magnet. The armature is of soft iron, supported at the extremity of a lever over the poles of an electro-magnet. The lever turns between supports on the axis, and tends to rise by the force of a spring regulated by an adjusting screw. When a current traverses the coils of the electro-magnet, the armature and lever are depressed, the click is put in gear, and the pallet of the escapement, released, turns with the axis. At the moment when the pallet passes under the lever, it relifts it, and depresses a screw, returning thereby the armature to the poles of the electro-magnet, and, at the same time, throwing the click out of gear.

The magnet employed consists of a permanent horseshoe magnet, with soft-iron cylindrical continuations on the poles. These continuations are each encircled by a coil of wire. When no current passes through the coils, the armature is attracted to the poles by the magnetism distributed in the iron. This force is opposed by the adjusting spring, which is so regulated that, the armature being in contact, a very weak current is able to neutralize the attraction.

The printing shaft has also the duty of correcting the movements of the type wheel, and of ensuring always that, at the moment of printing a letter, the type is in its proper position. This is effected by means of a curved cam h_2, on the axis *i*, Fig. 82. The instant the cam *h'* lifts the arm of the frame carrying the printing roller, the projection h_2 locks into the teeth of the wheel *H*, and adjusts, if it be necessary, its position. If, on entering the teeth *H*, the cam has to push the wheel forwards, or to accelerate the motion of the axis C C, the click *m* is pushed onwards, passing over one or more of the teeth of the ratchet wheel G_5, Fig. 81.

If, on the contrary, the cam has to retard the motion, the click pulls the ratchet wheel backwards, for which purpose the latter is not made rigid on the axis, but is formed of a disc held between leather washers supported by two plates of metal, fixed on the hollow shaft G.

The electric circuits of the apparatus are very simple. The bottom of the vertical shaft, Q, is connected to earth, and the upper part to one end of the coils of the electro-magnet, the other end being to line. One pole of a battery is connected to the levers *k* of the contact pins, the other pole to earth. At two corresponding stations the plates of the batteries must always be looking the same way, because the home apparatus is intended always to work as well as that of the distant stations, and the armature of its magnet is only liberated by currents in one direction.

When a current arrives, therefore, from the line, it passes first through the coils of the magnet, then through the vertical shaft Q, which it descends, and goes over from the screw in the jointed arm to the resting-piece, and from this to earth. When a current is to be transmitted, the operation consists principally in interrupting the earth circuit, and in inserting the battery into the break. This is done by the contact pins and jointed arm of *r*. A key being depressed, the arm *r* in its journey rides over the pin, and its screw is lifted up from contact with *r′*, which breaks the direct earth circuit. At the same time the contact of *r′* with the pin *k*, which is in communication with a pole of the battery through the lever K, sends a current from the battery through the coils of the magnet into the line.

Suppose two such apparatus properly adjusted at the extremities of a line of telegraph, the clockwork wound up, the electrical connections duly established, and the type wheels locked. The employé who desires to transmit presses down the blank key of his instrument; this pushes up the corresponding contact peg in the circle, and when the chariot arrives over the pin, the extremity of the piece rides over it, separating the earth contact, and introducing the battery into the line circuit. The current passes through the vertical shaft, the coils of the magnet, and line wire to the other station, where it circulates in the coils of the magnet, the vertical shaft, and goes to earth.

In traversing the coils of the magnets of both instruments, the current weakens the attractions of the armatures to the poles of the electro-magnets; the former are forced off by the spring, the screws are raised, and the levers at the same time depressed. The pallets, *h*, of the escapements, *h h*, are thereupon released, the axes, *i*, put into gear with I, and the type wheels released. During the revolution made by the axes *i*, the cylinders are raised by the cams, and lift the paper up to the printing wheels, at the moment when the latter are unlocked. No letter is printed, because the blank space in the type wheel occurs just there. The paper strips and cylinders descend again, the former advancing a step. The clicks are then disengaged from the ratchets, and the pallets, *h*, recaught by the levers, which were lifted up, causing the armatures to be pushed down again to the poles of the magnets.

If a key answering to any letter be now pressed down, the current is repeated the moment the chariot passes over the raised contact pin; the printing axis is put in motion, the letter printed, and the paper pushed on as before, and so on, until the message is completed.

It sometimes happens that the apparatus do not agree when one of the stations sends its message. In this case the employé at the receiving station advises his correspondent of it by giving him a signal; both then arrest their type wheels, and the transmission is recommenced, beginning always with the blank.

To avoid the inconvenience of irregular working which might arise from changes in the battery power, Hughes has adopted a method of short-circuiting the coils of the electro-magnet, the instant after the armature is released, so that the current, whatever may be its intensity, comes into play only long enough to effect the required weakening of the magnetic attraction.

Hughes' type printer has been considerably modified in America, with the object of rendering it less complicated and increasing the speed at which the type wheel can be made to revolve without injury to the parts. Fig. 83 is a plan of the printing mechanism attached to this modified instrument. The printing wheel I is carried on the main shaft of the instrument, which receives its motion from a transmitting cylinder; upon its upper surface are fixed six angular pins *h h*; a detent on the end of the escape lever H takes hold of one of these pins, whenever the circuit of the electro-magnet is broken, but instantly releases it when the circuit is closed. The effect of each electrical pulsation sent through the electro-magnet of the receiving instrument is, therefore, to release one of the pins *h*, allowing the printing wheel I to perform one-sixth of a revolution, when it is again arrested by the detent of the escapement

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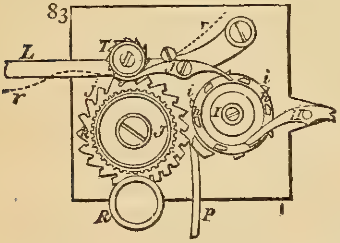

lever catching the next pin. Meanwhile the type wheel J is constantly revolving, so that the wheels I and J of the receiving instrument, and the transmitting cylinder of the sending instrument, perform the same number of revolutions in the same time. J has twenty-eight characters upon its circumference, and underneath these are two circles of teeth *j* and *k*, equal in number to the characters upon the type wheel. In operation, when the printing wheel I is released by the action of the electro-magnet, it performs, as before stated, one-sixth of a revolution. Two distinct operations are effected by this movement, first one of the teeth *i i* enters between two of the teeth *j* of the type wheel, and effects any necessary correction of the error in its position, by moving it a little forward or backward upon its axis; secondly, one of the pins *h* presses back the tail of the lever *j*, and this brings the paper strip *r*, which is carried by the cylindrical platen T into contact with the type. A circle of teeth upon T gear with corresponding teeth *k* on the type wheel, and the two revolve together as long as the contact lasts between the paper and the type, so that the feeding of the paper is accomplished while the impression is taking place. The types are inked by a felt roller R. The unison stop P is employed by the receiving operator to arrest the type wheel at zero or dash, when starting. It is thrown off the type wheel, and released at the first movement by one of the pins *h h* striking against the projection on the upper surface of the lever. The bar L supports the platen and its attachment: it is pushed back, so as to throw the impression lever out of gear with the printing wheel, when sending.

Phelps' electro-motor printing telegraph, largely used by the Western Union Telegraph Co., U. S., has the type wheel and printing mechanism operated by a local battery. This construction enables the working parts to be made much stronger than in the Hughes instrument, where the moving parts must necessarily be light. These parts consist of a transmitter with keyboard for closing the circuit, the receiver or printing mechanism, containing apparatus for maintaining unison automatically, the electro-motor, and the governor for speed. The transmitting apparatus and the type wheel of the receiving instrument are caused to revolve synchronously, under control of the governor, and each letter is printed by a single pulsation of the electric current, of determined and uniform length, transmitted at a given time. The motion of the type wheel is arrested while each letter is being printed, and is automatically released, the instant the impression has been effected. By this means a greater speed of revolution is given to the type wheel than it would be possible to attain by a step by step movement, and also letters which happen to come in direct sequence upon the keyboard, may be printed from, during the same revolution. The instrument is secured upon a base 18 in. by 23 in., and the keyboard consists of twenty-eight keys, together with a period and space. Directly in rear of the keyboard is a hollow column A, Fig. 84, which contains a circular range of twenty-eight vertical slide rods, corresponding to the keys, and the mechanism by which the circuit closer is actuated. The vertical slide rods *a* are connected with the keys, as in Hughes' printer, and are provided with angular heads a_1, projecting towards the centre of the hollow column; their inner ends rest in slots formed in a guide ring a_3, projecting from the upper surface of the guide plate A_1. The inner ends of these heads form a compact circle of about 1½ in. diameter. The pulsations of the current are transmitted upon the depression of the keys as follows:—In the centre of the hollow column A is a vertical shaft C, revolving continuously at 241 revolutions a minute, being driven by the wheel E, receiving its motion from the electro-motor. The speed of this shaft is controlled by a governor, and upon the shaft is a hollow flanged collar B, fitted loosely. When none of the keys are depressed, the collar B revolves with the shaft C, and the wheel E being coupled to them by a catch, pressed by a spring into one of four shallow vertical grooves cut in the outer periphery of the collar. A pawl is pivoted to the flange of the collar, and revolves almost in contact with the circle of twenty-eight ratchet teeth *d*, formed on the inner edge of a stationary annular plate D; the arm of the pawl extends through an opening into the interior of the drum, where it

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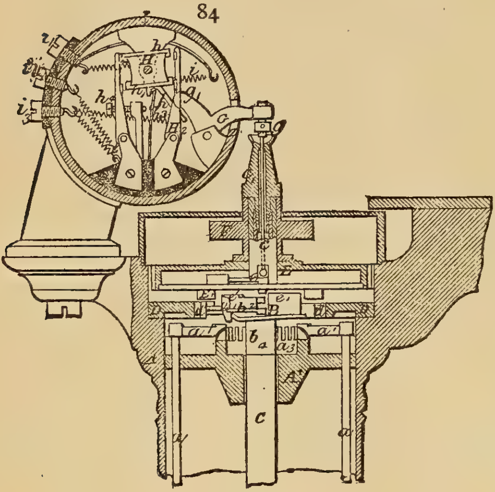

rests against a roller mounted upon a spring. The bottom of the collar B is formed into a flange, the under surface of which consists of two inclines, one of these inclines being short and sudden, and the other being gradual and in the reverse direction extending round the remaining portion of the circle. The flange revolves immediately above the inner ends of the angular heads of the slide rods. Upon the top of the collar are four projections with bevelled corners, each occupying one-eighth of its circumference. The horizontal pusher *e* mounted upon a spindle within the hollow wheel E, carries the short bevelled arm, extending downwards, and along the side of one of the projections e_1. The foot of a slender vertical rod *c*, rests upon this lever and extends upwards, through the hollow parts *e* of the shaft C, to the screw *g*. This rod *c* when pushed upwards serves to actuate the circuit closer. When one of the keys is depressed the corresponding slide is raised, and its angular head is pressed against the under surface of the flange *b* upon the collar B, which together with the shaft C is revolving at the rate of four revolutions a second. When the incline of B passes over the elevated slide head, the sharp head of the pawl is struck by it. In consequence of its inclined form the pawl is forced outward, and into contact with the opposite ratchet tooth *d* in the plate D, by which the rotation of the collar is arrested at that point, although the shaft C and wheel E continue to revolve as before. On the under side of the wheel E are four wedge-shaped cams E E_1, and after the shaft C and wheel E have moved through a quarter of a revolution, the collar remaining stationary, the next succeeding cam strikes the head of the pawl, forcing it back into its original position. At the same time a catch drops into the next succeeding groove in the collar B, which then revolves with the shaft C, until arrested by the depression of another key.

When the key is depressed no action takes place, until the head of the pawl in its revolution arrives at the corresponding slide-rod head, and the collar is immediately arrested during the time in which the shaft C is making a quarter of a revolution. At the end of this time it is released by the automatic action of the mechanism, and permitted to revolve with the shaft as before; while the collar B is stopped, the bevelled end of the pusher *e* passes over the projection e_1, raising the rod *c*, within the hollow shaft C, and operates the circuit closer. As the shaft *c* makes four revolutions a second, the collar B is stopped for $\frac{1}{16}$ of a second by the depression of each key, and as the length of the projection e_1, which determines the length of time during which the rod is elevated, and the circuit closed is one-eighth of the circumference of the collar, the duration of the electric pulsation produced by the elevation of the rods c will be $\frac{1}{28}$ of a second.

The circuit closing mechanism admits of either the single current or the double current system being employed, by change of connection. This part of the apparatus is enclosed in a cylindrical case I, fitted with plate-glass heads. H is a quadrangular plate of ivory mounted upon a rock shaft, upon which is also fixed an arm projecting downwards; upon the upper and lower edges of the insulating plate H, are fixed metallic bars h h_1. A spiral spring attached to the insulated screw i, takes hold of a short arm projecting upward from the axis of H, and the tension of this spring keeps the arm h pressed against the friction roller g_1, upon the lever G, and the latter in turn presses downwards by means of the adjustable screw g upon the vertical rod c. The spring also serves to conduct the electric current from the screw i_1, which is connected with the negative of the main battery, to the bar h_1; a second screw directly behind i_1 and insulated from it, is attached to the copper pole of the battery, and is also connected by means of a curved wire and spring i to the metallic bar h_1. H_1 and H_2 are two upright contact levers connected respectively to the line wire, and to the earth. When the apparatus is arranged for the double current system, the negative current flows to line at all times, when none of the keys are depressed, but when the rod c is raised, by the action of the transmitting mechanism, the polarity of the current upon the line is reversed, by the action of a lever G upon the arm h, shifting the position of the plate H, and bringing the negative pole of the battery into connection with the earth. Pulsations thus transmitted are conducted through a relay, connected with the sending as well as the receiving instrument. With the double current system a polarized relay is used.

The printing mechanism, Fig. 85, is arranged upon a horizontal circular plate, supported by a bracket upon the hollow column A. The type wheel T is rigidly fixed upon the same axis with and directly above the wheel T_1 of the same diameter, provided with twenty-eight ratchet teeth. The wheels T and T_1 are upon a sleeve, and are attached, by means of a friction plate, to the axis of a toothed wheel receiving its motion from a wheel not shown in the

Fig., through the intervention of an idle wheel. As these wheels have each the same number of teeth, they must revolve synchronously. The type wheel T is inked by means of an ink roller *t*, mounted upon a horizontal swinging arm, and constantly pressed against the type wheel by a spring; the star printing wheel K controls the mechanism, and itself is under the control of another electro-magnet M; it arrests the type wheel when a letter is to be printed, forces the platen and paper into contact with the type wheel, moves the paper forward after the letter has been printed, and releases the type wheel. The electro-magnet is actuated by a battery connected with the receiving relay. To its armature is fixed a lever *m*, armed with a detent m_1, which takes hold of one of the points *k* of the printing wheel, when no current is passing through the magnet. The detent is kept in position by a spring. The printing wheel K, being connected to a wheel by a frictional coupling, revolves with the latter when not kept in check by the detent. The printing wheel K has six angular studs or pallets projecting from its circumference, to serve as stops, upon which the detent m_1 successively acts. Two concentric rows of vertical pins are inserted upon the upper surface of the printing wheel, and there are six of these pins in each row; the outer row of pins *k*, acts upon the stop lever which arrests the type wheel on the inner row *n*, and acts upon the platen and upon the mechanism while moving the paper. Between each pair of pins *k*, *n*, is placed a central circular pin.

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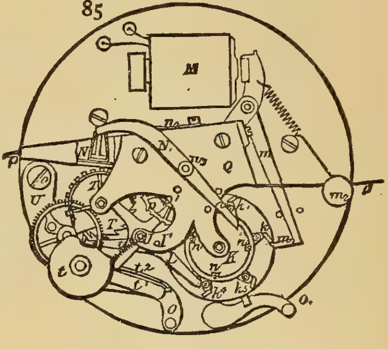

When a letter is to be printed the detent m_1 is lifted by the action of the electro-magnet, the pallet *k* is released, and the printing wheel K carried forward one-sixth of a revolution, by its frictional connection with the wheel beneath it. This movemant of the printing wheel produces the following results. An angular projecting stud at the end of the type-wheel stop lever L is caused to pass between the pallet k_4 and the pin; as this lever turns upon a fulcrum at I′, the detent *l* at its opposite extremity is inserted between two teeth of the wheel T_1 and the elevation of the type wheel T is arrested. When the circular pin moves round, it bears against the inclined surface of the top, and forces the lever L into the position by which the type wheel is locked. The lever is retained in its position by a pin as it glides along the curved surface, holding the type wheel in check until the inclined face of the succeeding pallet k_5, coming into contact with the inclined surface upon the lever L, returns the latter to its normal position in readiness for the next rotation. Upon the release of the printing wheel K by the detent m_1, the type wheel is arrested and held in check while the printing wheel makes one-sixth of a revolution, and is then released. The device for moving the paper forward is a modification of the mechanical movement known as the Geneva stop, the convex tooth being omitted. In all type printing systems it is necessary that the transmitting mechanism of one instrument and the type wheel of the other should be in exact correspondence, and to effect this means must be adopted to ensure their starting together. In the Hughes instrument this is accomplished by a simple stop lever, and in Phelps's printer the type wheel is automatically arrested at the zero point, whenever it is permitted to make a few revolutions without printing. Upon the upper surface of the wheel T_1, Fig. 85, directly under the type wheel is a pin, filed to a flat surface on the side towards which the wheel revolves. J is a three-armed stop lever turning upon a fulcrum. U is a toothed wheel mounted so as to revolve freely upon a pin fixed in the horizontal lever O, by means of which it may be thrown in or out of gear with the corresponding pinion in the type wheel axis, at the pleasure of the operator. Ordinarily it is kept in gear with the pinion, and receives from it a slow rotary motion. A curved arm fitted to the arm of the stop lever J, is constantly pressed against the revolving axis of the wheel U, and has the effect of slowly and continuously swinging the stop lever J towards the left, whenever the type wheel is in motion.

If the printing wheel K continues stationary, in the course of four or five revolutions of the type wheel, the lever J will swing round into such a position, that the stop which projects downwards from the end of the arm, will be thrown into the path of the stop upon the wheel T_1, which will come into contact with it in its next revolution. The type will be arrested with its dash or blank space opposite the platen, where it will remain until the printing mechanism is again operated. Immediately the printing wheel K is released, by the action of the electro-magnet, the stop lever J is thrown back into position, because its third arm lies in the way of the second pin of the circular series upon the printing wheel. So long as one or more letters are printed at every revolution of the type wheel, a continual succession of the pins will strike against the arm, and prevent the stop lever J from being swung far enough to arrest the type wheel, unless the operation of printing is suspended during several successive revolutions of the type wheel axis, and the type wheel will be automatically arrested. The electro-motor and its governor are mounted upon the base of the instrument, and consists of eight electro-magnets arranged in a circle within which a revolving shaft turns a circle of soft iron armatures. The magnets act successively as the armatures come within their influence, and cease to act just as the armatures arrive opposite to the poles of the magnets; by this means constant attraction is exerted upon the armatures. The motor is provided with a centrifugal governor, which acts to reduce the quantity of electricity flowing through the magnets, whenever the speed is too great. The local battery which drives the motor consists of two large Bunsen cells, charged with Poggendorff's bichromate solution in contact with the carbons in the porous cell, and diluted sulphuric acid in the outer or zinc cell; these cells being 5 in. diameter and 6 in. in height. This is sufficient battery power to run the motor continuously for fifteen hours, without requiring renewal of the bichromate solution. The system is worked direct at full speed, without relay, between New York and Chicago, a distance of 1000 miles.

Figs. 86, 87, relate to Wheatstone and Stroh's devices introduced in 1872 in the construction of step-by-step telegraphs, the object of which is to enable the indicator of a large dial, or the dial itself, to be moved rapidly with the same certainty as the indicators of small dials.

To attain this object the propelment of the index is due to the action of a maintaining power, limiting the work performed by the transmitted currents to the controlling of the scape wheel, a special arrangement obviating the retarding effect due to the weight of the index hand.

On an axis *a*, Fig. 86, driven by clockwork gearing with the pinion *x*, is firmly fixed an index hand P and an arm *z*. At the extremity of this arm a pinion *d* centred at *c* and gearing with the stationary wheel D, a segment only of which is shown, carries two equal arms *e e*. Mounted loosely on the axis *a* is a scape wheel A, to which one end of a light spiral spring S is attached, the other end being fixed to the axis *a*, so that the scape wheel remaining stationary and the axis *a* revolving, the spiral spring S would be wound up, and conversely the axis *a* remaining stationary and the scape wheel free to move, the spiral spring in unwinding itself would tend to propel the scape wheel forwards. To the centre of the scape wheel A is fixed the piece *f* carrying at its extremity a stop *n*, which when the scape wheel is at rest is met by the end of one of the arms *e e*, attached to the pinion *d* or to its axis, and thereby the revolution of the axis *a*, and consequently the pointer P, prevented. The control of the scape wheel is effected by the pallets B B, to which an oscillatory motion is communicated by any suitable electro-magnetic arrangement, such as that shown at E E, in such a way as to allow the scape wheel to advance with a step-by-step motion, one half tooth for every movement of the pallets. It follows that with every movement of the pallets B B, the scape wheel A driven by the spiral spring S will advance, and this forward movement of the scape wheel will, by withdrawing the stop *n*, release the arm *e* and allow the maintaining power gearing with the pinion *x* to propel the axis *a*, the pointer P, and the arm *z*, and thereby to wind up the spiral spring S. The pinion *d* carrying the arms *e e*, at the extremity of the arm *z* and gearing with the stationary wheel D, will thus rotate like the sun and planet movement, until the scape wheel coming to rest locks the whole again, by presenting the stop *n* to either of the arms *e e*. The number of teeth on the pinion *d*, the stationary wheel D, and scape wheel A, are so arranged that for every half tooth of the scape wheel liberated by the pallets B B, the arms *e e* attached to pinion *d* make one half revolution. The pointer P advances one space on the dial for every half tooth of the scape wheel so liberated, and thus while the move-

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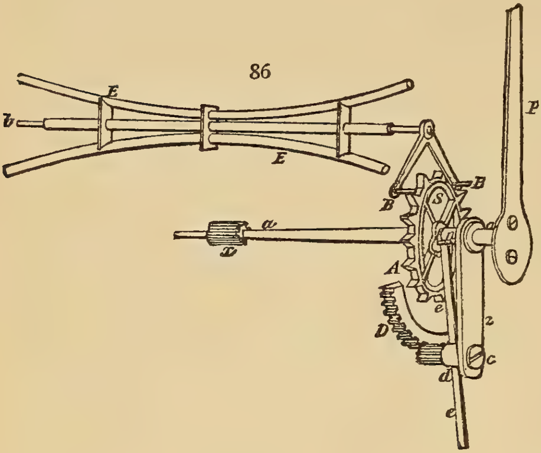

ments of the pointer are independent of the step-by-step motions of the scape wheel, the latter completely controls the starting and stopping.

In applying this arrangement to type printing telegraphs, it is used for regulating the motion of the type wheel, and the stamping of a letter on the paper strip is effected automatically, immediately after the cessation of the last of the electric currents necessary to bring the type wheel to the requisite position.

Mounted on the axis *a*, Fig. 87, in place of the index hand is a wheel R, gearing with another wheel Y fixed firmly on the arbor of the type wheel. By means of these wheels the maintaining power moving the type wheel is controlled by the pallets B B. Also mounted on the arbor of the type wheel is a saw-toothed wheel Z, and in play with the teeth of this wheel is a pin fixed into the extremity of the arm E, this arm being centred at *e* and continued in a light rigid bar E_1, bearing on a friction wheel *f*. During the rotation of the wheel Z the pin cannot rest between any of the teeth, and the arm E is therefore kept up. The pin on E passes in its upward motion against a segmental arm *d* centred at C, at which also is centred the arm *n* bearing against a pin in the

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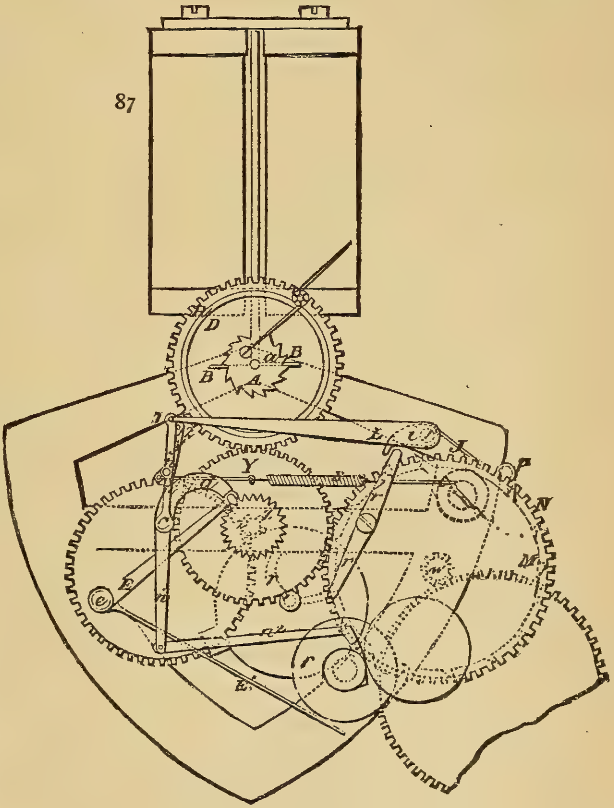


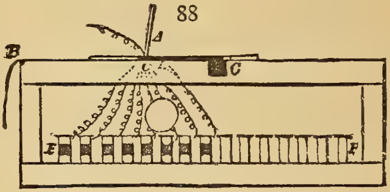
segmental arm *d*, and sustains these two arms, keeping the releasing arm L, which is centred at *i*, free from the pin 1 at the end of the arm *n*, and allowing a bent end of the releasing arm L to rest upon the pin 2 in the arm *y*, which is centred half-way up the arm *n* and kept in position by a spiral spring S. A continuation n^1 of the arm *n* has pivoted at its extremity a light bar n^2 bearing upon friction wheels.

When the rotation of the wheel Z ceases the pin on E and the arms *d* and *n* fall, and before the end of the releasing arm L can engage with pin 1, the check piece is liberated from its position of rest on pin 2, and the arm L falls. A transverse groove in the arbor of the arm L retains the end of a piece J, jutting from the axle of a pinion P, gearing with a wheel N fixed on the arbor of a second wheel M, having widely spaced teeth, and called the stamping wheel. With a pinion *w*, also on the arbor of the stamping wheel, a maintaining power, separate and different from that imparting motion to the type wheel, is in gear. The fall of the arm L liberates the piece J, and this piece in making one revolution before it again engages in the groove of the arbor of the arm L, permits the stamping wheel to be carried forward one tooth by the maintaining power in gear with it. The tooth of the stamping wheel coming into contact with a touch piece, causes the printing hammer to be lifted against the rim of the type wheel. Consequently, the letter immediately presented to the face of the printing hammer, is printed on the paper strip which intervenes between the type wheel and the hammer. The action on the printing hammer is direct, but in the case of the arm L a series of levers *r*, *r*, *r*, are brought into play. The type wheel is adjusted to zero as in Fig. 86.

Fig. 89 is a plan of sending instrument of E. A. Cowper's writing telegraph, Fig. 88 being an elevation of the same. The writer holds the pen, which is rigidly connected to the travelling contacts, and also, as at A^1 A^2, to the batteries. The slip of paper on which the message is written is moved somewhat in the same way as in a Morse instrument; in fact, the Morse clockwork can be easily used for the purpose. Thus the paper travels under the pen instead of, as in ordinary writing, the pen travelling over the paper. Two sets of thin metal plates C C form the contact apparatus, D are the light connecting rods, the ends of which make contact with the plates; F F are the resistance coils connected to the contact plates, one coil for each plate, except the first of the series, which is connected to line.

It will be noticed that the strength of the current entering the line, depends upon the plate with which contact is made by the connecting rod. As the rod travels from the first of the series the resistance increases, the current having to pass through N — 1 resistance coils, as well as the line wire, N being the number of plates from the first of the series, to the point at which contact is made. Generally, however, as one contact piece travels from the first of the series, the other travels towards the first of its series, and thus, while the current decreasing varies in one line, the variation is increasing in the other. A slight knowledge of co-ordinate geometry is required to plot the curve of any letter, and to calculate the variations in the strengths of the currents. Figs. 90 and 91 are respectively an elevation and plan of the thin metal plates, which are insulated the one from the other by paper soaked in paraffin. The receiving instrument, Figs. 92 and 93, differs from the sending instrument; H H are light, soft iron bars on delicate bearings, having the ends surrounded by the coils I I, to which the bars form a movable core. Through these coils the varying currents of the line are sent, which, of course, have a varying action on the core. J J are four permanent or electro-magnets, between the poles of which the coils just named are placed; K is a Clark siphon pen, which is adjustable from the bridge L, and the ink reservoir is at M. The light connecting rods N N transmit the motions of the movable cores to the pen; O O are springs to enable the pen to resist the pull of the magnets, the connections are shown in O^1, O^2, O^3, the latter being attached to a fixed post O^4.

88



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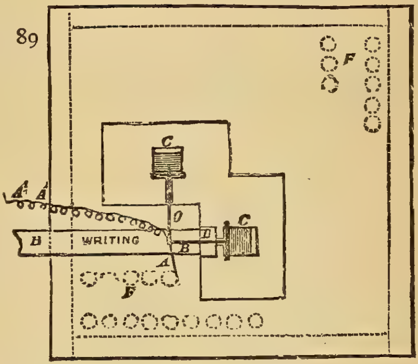
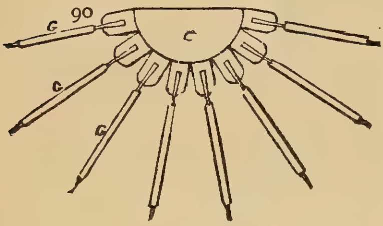


As the currents sent through the line wire by the sending instrument vary in strength, and cause the light bar of soft iron to move with varying power by its attraction to the stationary magnets; and in order to cause it to take its proper position according to each vibration in power, a varying resistance is opposed to it, such as a spring which requires increased power to compress it the more it is compressed, so that the action of the soft iron bar, combined with that of a precisely similar bar actuated by the second line wire, will cause the position of the pen in the receiving instrument to follow the position of the pen in the hand of the operator at the sending instrument, and thus form the letters. The total strength of the spring or varying resistance can be regulated at will, so that the letters formed by the pen shall be of the same proportionate height and width, as the letters written by the operator at the sending instrument.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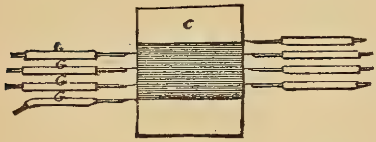
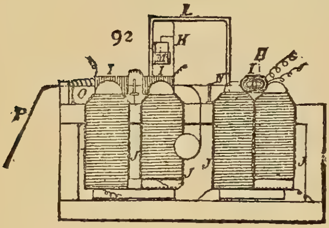

91

Electric Lamps.—Electric lamps or burners may be divided under two heads; those in which the voltaic arc is caused to exist between the two portions of an interrupted circuit; those in which a continuous portion of the circuit, being a bad conductor, is heated to incandescence by the passage of the current. It is probable that this division being arbitrary and not generic, may at any time be overturned by a new invention based upon principles that do not appear in lamps at present invented.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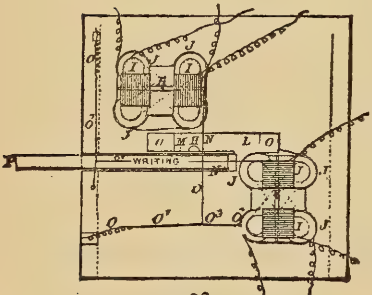
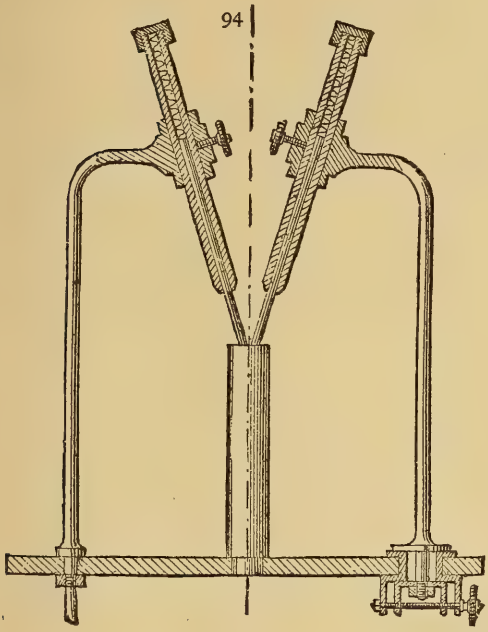

93

Foucault, in 1844, substituted retort carbon for common wood charcoal, as the substance for electrodes, and this discovery opened up a practical application of the electric light to photographic purposes. The lamp was simply a holder for the carbon rods, and required help from the hand of the operator. Trials of the light were made in the Place de la Concorde, Paris, by M. Deleuil, who had previously experimented with carbon placed in a receiver from which the air had been exhausted.

Staite and W. Edwards, in 1846, introduced a lamp, Fig. 94, in which two carbon electrodes are enclosed in small cases, meeting obliquely on a refractory and badly conducting substance. The points are brought into place, as consumed, by springs. A sliding-piece and screw beneath the base board enable the length of the voltaic arc to be regulated.

94



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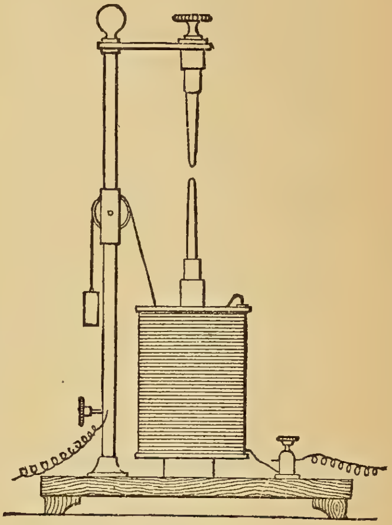


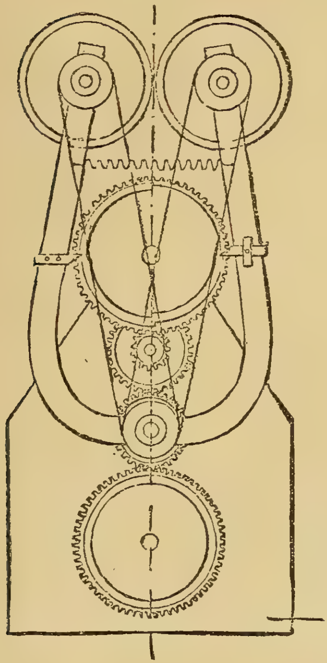
Staite and Petrie, as well as Foucault, in 1848, devised a method by which the current regulated the distancing of the carbons. This was based upon the phenomena that an electric current can cause magnetization according to its strength; that the voltaic arc as part of the conductor, reacts upon the current. This lamp, however, was never introduced into practical use; in principle it was similar to Archereau's lamp.

Fig. 95 is of Archereau's lamp, the basis of many ideas, and one of the most simple and effective of its kind. It consists of a hollow coil of copper wire, with a vertical standard, two carbon carriers, and a counterpoise. The upper carbon is carried by a bar, sliding into and turning at the extremity of an insulated horizontal copper bar, in connection with the negative pole of the electric source. The lower carbon rests on a cylinder, half of copper, half of iron, rising or falling in the hollow bobbin. The positive pole of the electric source is attached to one end of the wire coil, and the other end to the interior cylinder of the coil; a weight counterpoises the lower carbon holder. When the current passes in the wire, it produces magnetic action, causing the cylinder to descend into the bobbin, and to reduce the strength of the current. When the magnetism is too weak, the action of the counterweight raises the cylinder. Initially the carbon points must be brought into contact, to establish the electric circuit. When the voltaic arc is formed, the cylinder remains fixed in the coil, and the counterweight is motionless. As the voltaic arc increases in length, and the current is weakened, the lower carbon rises, until the current again attains sufficient power.

T. Wright, in 1845, caused the voltaic arc to play between discs of carbon, and Le Molt, in 1849, improved upon this idea. Fig. 96 is the lamp described. Le Molt claimed the use of all carburetted matter, as electrodes producing the light, especially that of retort carbon, and the two combined movements of rotation and approximation, at given intervals, of two discs of variable depth and diameter. The discs are maintained, with regard to one another, in a parallel attitude, vertical or horizontal, or preferably, in positions at right angles, and conveniently distanced to produce the electric light. The discs revolve regularly upon two metal axles, put into connection with the poles of the generating apparatus, and presenting, successively, by the combined rotation and approximation, all the extreme points of their circumferences to the production of the light; in such manner that at each revolution of the discs, the latter approach one another by the distance which they had separated by the combustion of part of the carbon, and thus are always replaced in the same position of invariable distance. Le Molt introduced the purification of the carburized matter forming the electrodes, by more or less prolonged immersion in nitric and muriatic acids, and subsequently in fluoric acid. This lamp allowed of twenty to thirty hours' continuous light; but the intensity of the light is less than that obtainable with vertical carbon rods.

Another typical form of lamp is that of Lacassagne and Thiers, who, in 1855, substituted for clockwork, which had then been introduced into lamps, a float acting in a bath of mercury. A cylinder contained a float upon, and in connection with, the mercury; one carbon electrode rested upon this float. The other carbon electrode was fixed in the same axial line above the electrode supported on the float. As the carbon points consumed, so the float rose; but a means of arranging the rise to occur at the proper time was necessary, and was thus supplied. Mercury from a reservoir, having entered the float cylinder, passes through a tube placed in an electromagnet. In this tube is an indiarubber valve, opened and closed by a soft iron armature, withdrawn by a spring opposing the action of the electro-magnet. The opening of the valve admits mercury to the float cylinder. As the distance between the electrodes increases, the magnetic attraction decreases, and the valve opens, the incoming mercury raising the electrode.

96



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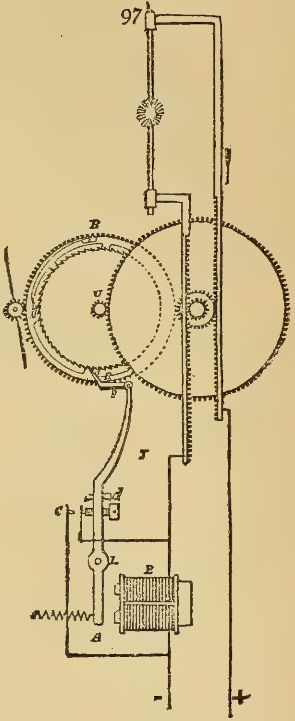


This lamp is the basis of many subsequent ideas, some of which omit the regulating apparatus, and employ the mercurial bath simply to raise the carbon rod against a disc of carbon, as the rod is consumed.

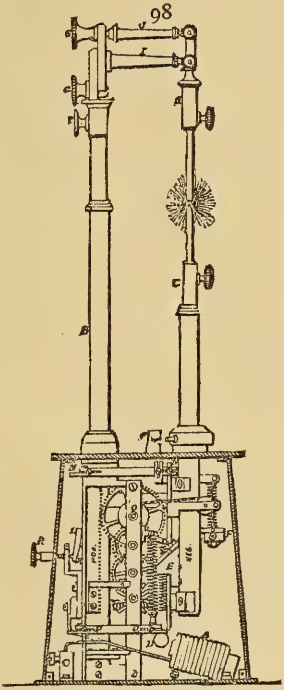
These lamps, however, have not, as constructed by their inventors, met with practical application. The various modifications introduced do not detract from the merit of the original inventions, but are additions that have become expedient, under somewhat different circumstances attending the use of the powerful currents derived from magneto- and dynamo-electric machines. If the accounts were continued chronologically; there would follow a description of Duboscq and Foucault, in which clockwork was employed to distance the carbons. These will be presently referred to, but it is first necessary to point out that all complication is to be carefully avoided, and that a lamp to be effective must need no skilled attendance, such as a clockwork movement would entail.

Lamps in very general use are the Siemens and the Serrin. In the Alteneck-Siemens lamp, Fig. 97, the position of the carbons is regulated by the weight of the upper carbon holder, which tends to bring the carbons together. The carbon points are separated by a small electro-magnetic motor. The upper carrier is connected to the lower by rackwork and tooth wheels. When, by reason of the carbon points approaching too closely, the current becomes too strong, the electro-magnet E attracts the armature A, held back by a spring, which keeps the lever T, centred at L, against the stop *d*. When the electro-magnet overcomes the effort of the spring and attracts the armature, contact is made at *c*. Immediately the current ceases to pass through the magnet, the armature is released. The lever T is thus kept in oscillation and communicates by a pawl *s* a rotary motion to a fine tooth wheel U, and by the help of the train and racks separates the carbons. A pin R, against which the pawl strikes when the armature is retracted by the spring, compels the pawl to leave the teeth of the ratchet wheel, and allows free motion to the racks. That the carbons may not run together too rapidly, a fly *w* is employed.

If alternating currents are used with this lamp, the oscillations of the armature are produced, not by making and breaking contact, but by change of polarity of the current.

Several other forms of lamps have been introduced by Siemens. One of these, on the principle of the Archereau lamp, has its carbons separated by the action of a cylindrical armature which is drawn into a hollow bobbin. In another form, the carbons are placed inclined to each other side by side, one being pivoted at its lower extremity, to which is attached a short arm carrying an armature of an electro-magnet. As soon as the electro-magnet, which is in the lighting circuit, is excited, the carbons are drawn apart and the arc established between them, as in the Rapieff and Wilde systems, to be presently described.

Serrin's lamp, Fig. 98, consists of an electro-magnet A, a bar B, a bar C carrying the negative carbon, an armature D, abutment E, spring F, excentric G, positive carbon holder H, tie piece, fixed, I, adjustable tie piece J, tension lever K L, double parallelogram M N P Q, train of wheels O, adjusting screws R and S, clamp screw T, and ivory stop V. The weight of the top carbon causes the points to be brought together. The top carbon holder bar is racked at its lower end, and in the descent engages with a tooth wheel of the train O. On the same axle is a pulley of diameter half that of the wheel. This pulley follows the motion of a smaller pulley, by means of a link chain. The chain is fixed to a standard F, attached to the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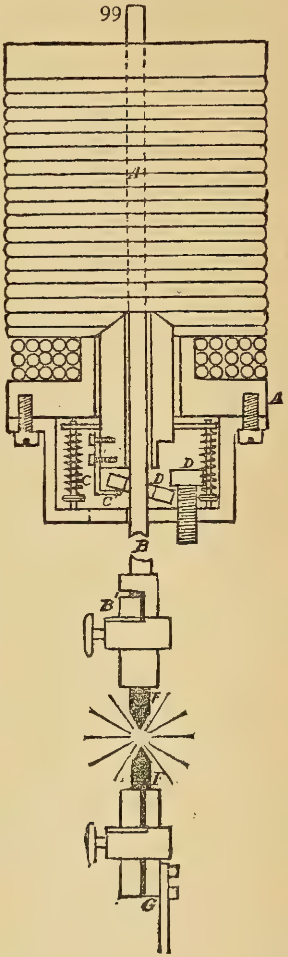
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tube of the negative carbon holder. According to the dimensions of the first pulley the negative carbon holder is carried to a distance half that through which the lower carbon holder descends. The descent of the upper carbon is regulated by a fly, which also carries a star wheel.

The proper distance between the points is obtained by means of the double-jointed parallelogram M N P Q, controlled by the soft iron armature D and electro-magnet A. The influence of the weight of the carbon holder on the jointed parallelogram is counterbalanced by two spiral springs, one attached to the lower horizontal side and to a fixed arm, the other, connected to the movable vertical side of the parallelogram, is also attached to the end of a bent lever L K, and can be adjusted to the screw R. The distance through which the armature D is attracted varies with the intensity of the current. The bar of the negative carbon holder is connected to the vertical moving side of the parallelogram, which is submitted to two counterbalancing forces, the weight tending to cause it to fall, and the springs to raise it. The action of the electro-magnet is to cause the parallelogram to descend. The vertical movable side of the parallelogram carries a jockey E, the point of which, as it descends, enters between the arms of the star wheel, detaining the movement of the train and racks. The distance of the carbons apart, giving the best light for mean strength of the current, is regulated by the tension given to the spring in connection with the lever L K.

Girouard's lamp regulator consists of a clockwork movement for bringing together and separating the carbons; and a regulator or relay, placed near the lamp and operated by a small battery. The relay receives a small amount of the lighting current and controls the clockwork movement.

Carré's lamp employs a double solenoid instead of an electro-magnet. The armature solenoid is S-shaped, and is centred so as to enter at each of its extremities into a hollow curved bobbin. The object of this arrangement is to obtain greater space, through which the carbons may be separated, than is obtainable with an ordinary electro-magnet and its armature.

Foucault and Duboscq's lamps, superseded in the lecture-room by the Serrin and other lamps, contain a clockwork movement, which has to be wound up, regulated by escapement, which is controlled by an electro-magnet in the circuit.

Gaiffe's lamp is a modification of that of Archerau, with the addition of a rack and pinion for raising the top carbon, which is aided in its descent by a spring that is coiled when the carbons are drawn apart. The electro-magnet is covered with more convolutions at the base than at the top, so that when the current becomes weakened by the separation of the carbon points, it may have its magnetic effect still powerfully maintained.

Fig. 99 is a section of one of the Brush lamps; A is a helix of insulated wire, A′ an insulated plate, C an iron core, B a rod, D a brass ring, F F carbons, G lower carbon holder. The Brush lamp contains no clockwork or similar mechanism, and the movement of the upper carbon, actuated by gravity, is controlled by an annular clamp, which surrounds the rod carrying the carbon. When the lamp is in operation, one side of this clamp is lifted by magnetic action; this causes it to grasp and raise the rod, and thus separate the carbons. As the carbons burn away, the magnetic action diminishes, and the clamp and rod move gradually downward, maintaining only a proper separation of the carbons; but when the tilted clamp touches the supporting floor from which it started, any farther downward movement releases the rod, and allows it to slide through the clamp, until the latter is again brought into action by the increased magnetism due to the shortened arc between the carbons. In continued operation, the normal position of the clamp is in contact with its lower support, the office of the controlling magnet being to regulate the sliding of the rod through it. If, however, the rod accidentally slides too far, it will automatically be raised again, and the carbon points maintained in proper relation. Each magnet helix is first wound with a few layers of coarse wire, through which the main portion of the current passes. Over this coarse wire is wound a very much greater length of fine wire, not shown, having its ends connected with the terminals of the lamp, but in such a manner that the electric current shall pass through it, in a direction opposite to that in the coarse wire. The fine wire forms a circuit of high resistance, which is independent of the arc between the carbons, and is always closed. It follows from the difference in direction of the current in the two helices, that the fine wire helix will constantly tend to neutralize the magnetism produced by the coarse wire or principal helix. The number of convolutions of the fine wire helix and its resistance are so proportioned to the number of convolutions in the principal helix and its resistance, together with that of the normal voltaic arc, that the magnetizing power shall be much greater.

Notwithstanding the small amount of current which passes through the fine wire helix, about 1 per cent. of the whole current, its magnetic power is considerable, owing to its great number of convolutions.

When a number of regulators provided with these double helices are operated in a single circuit, uniformity of action will be maintained; for when any lamp gains more than its normal arc, the resistance of its main circuit is increased; more current is consequently shunted through its secondary helix, and the resultant magnetism is diminished, allowing the carbons to approach. On the other hand, if an arc becomes too short, its resistance is reduced, and less current is shunted through the corresponding helix, and its carbons are drawn farther apart. Although the general strength of the current, operating a large number of these lamps, does not vary, each lamp performs its regulating functions through the agency of varying magnetism, precisely as though it were the only lamp operated. In practice, the resistance of the fine wire helix or helices in each lamp is rather more than 450 ohms; while the resistance of the coarse wire, various connections, carbons, and voltaic arc, in each lamp used with a 16-light machine, is about 4½ ohms. Hence not more than 1 per cent. of the whole current is diverted from the arc.

The resistance of the coarse wire helix, copper-coated carbons and connections, in each lamp is very small. To determine this resistance, sixteen lamps were connected in series in the usual manner, about 200 ft. of No. 10 copper circuit wire being used. Full-length carbons were then placed in the lamps, and the upper and lower carbon of each lamp were connected by means of a strip of sheet copper, wired to each carbon. The resistance of the whole set was then measured, and found to be 2·10 ohms, showing a resistance for each lamp with its carbons, of ·139 ohm. This is 2·91 per cent. of the whole resistance of the lamp when in operation. To this loss must be added the 1 per cent. due to that amount of current diverted from the arc by the fine-wire regulating helix, making a total loss of 3·91 per cent. The remaining 96·09 per cent. of the whole energy absorbed in each lamp, appears in the arc between its carbons.

The shunting or short circuiting device in each lamp, consists of a small magnet core, surrounded by a coarse and a fine wire helix similar to those of the working magnet. No current passes through the coarse wire until the magnet which it surrounds has raised its armature. The latter, together with the coarse wire, then form a part of the short circuit established through the lamp. The fine wire helix of the shunt is put in the circuit of the fine-wire regulating helices. During the normal operation of the lamp, this fine wire helix exercises a magnetizing influence on its enclosed core, which thus attracts its armature with a certain degree of force, but not enough to lift it. But when, through the exhaustion of the carbons in the lamps, or from their failing properly to feed together, the arc between them becomes considerably lengthened, developing an abnormal resistance, an increased current will be shunted through the fine wire helix, the iron core of the latter will raise its armature, and establish a circuit of low resistance independent of the carbons.

When the short circuit is closed, very little current circulates in the fine wire helix, and the magnet would drop its armature and open the circuit, were the armature not retained by some means other than the magnetism due to this helix: but the coarse wire helix surrounding the same iron core is now brought into action, and the armature is retained.

The carbons employed in these lamps are covered with a thin coating of copper, and are 12 in. long. They burn, without renewal, about eight hours, and during this time about 9½ in. of the positive, and 4 in. of the negative are consumed. When it becomes desirable to operate the lamps more than eight hours continuously, double-rod lamps are used. In each of these lamps two movable rods and two sets of carbons are employed. The rods are placed 3 in. apart, and each is moved and controlled in the manner described. Both rods are actuated by a single magnet, the same as that employed in the single-rod lamp. The simple lifting mechanism connected with the magnet is so arranged, that one of the rods is lifted slightly in advance of the other. When the electric current first passes through such a lamp, the two sets of carbons, having their members in contact, will divide the current between them; but as soon as the members of one set are separated by the action of the magnet, the whole current is thrown through the other set, without showing any spark between the members of the set first separated. When the continued action of the magnet separates the remaining pair of carbons, the voltaic arc appears, and the light is established. The clamp which was the last to raise its rod will be the first to release it, when a forward movement of the carbon becomes necessary. Hence, the set of carbons which first commenced to burn, will continue to do so until consumed, the other set remaining separated as at first. But when the burning carbons are exhausted, and can no longer move forward, any further effort of the magnet to feed them, will at once bring the reserve set of carbons into contact; the whole current will then pass through this set, leaving the other carbons without current, and permanently separated. The reserve set of carbons will now be separated by the magnet, and burn continuously. In practice, the transfer of the voltaic arc from one set of carbons to the other is accomplished instantaneously, and is scarcely noticeable.

By means of these double-rod lamps, a system of lights may be maintained in continuous operation sixteen hours without attention. This is sufficient for the longest winter night. But by introducing three rods, and three sets of carbons in each lamp, the lights may be maintained for twenty-four hours. In this case the clamps lift their rods successively, and feed them in the reverse order, as before.

In working, sixteen lamps are employed on one circuit, which for 200 ft. may be No. 10 copper wire, and each of the sixteen lamps normally, has an arc of about one-twelfth of an inch.

Measurements have been made for the purpose of determining the difference of potential between the terminals of each lamp, with the sixteen lamps adjusted to furnish arcs as nearly equal as possible. An opposing battery method was employed, and gave as result a difference of 42·46 Daniell's elements.

As the report by C. F. Brush includes the only published measurements of the power absorbed in working more than one light on a single circuit, the resistance of the components of the circuit and the distribution of work are given in the following statement:—

EXPENDITURE OF POWER IN WORKING SIXTEEN LIGHTS ON A SINGLE CIRCUIT. BRUSH SYSTEM.

Resistance of dynamo-electric machine	10·55 ohms.
Resistance of external circuit	72·96 "
Total resistance of circuit	83·51 "
Resistance of voltaic arcs	70·86 "
Percentage of current available for external work	87·36 "
Percentage of current appearing as heat and light in sixteen voltaic arcs	84·00 "
Electro-motive force of current	839·02 volts.
Volume of current	10·04 webers.
Total driving power required	15·48 h.p.
Driving power absorbed in production of current	13·78 "
Energy of current expressed in h.p.	11·285 "

Percentage of gross power converted into current	72·90 h.p.
Percentage of absorbed power converted into current ..	81·89 "
Percentage of gross power appearing in arcs	61·24 "
Percentage of absorbed power appearing in arcs	68·79 "

Referring to the electrical measurements, there is a current in 10·04 webers, with a total resistance of 83·51 ohms. The value in foot-pounds of any current is $(C^2R \times t)$ 0·737335, where C is the current in webers, R the total resistance of the circuit in ohms, t the time in seconds, and 0.737335 the equivalent in foot-pounds of one weber for each ohm a second. Hence, the value in foot-pounds a minute, of the current from the 16-light machine, is $10·04^2 \times 83·51 \times 60 \times ·737335 = 332410·58$. This divided by $30,000 = 11·285$, which is the energy of the current expressed in h.p. Again,

$$\frac{11·285}{15·48} = ·729;$$

hence, 72·9 per cent. of the total power applied at the pulley of the machine was converted into current. As 84 per cent. of the entire energy of the current appeared in the voltaic arcs, 72·9 multiplied by $·84 = 61·24$, the percentage of the total driving power appearing in the arc.

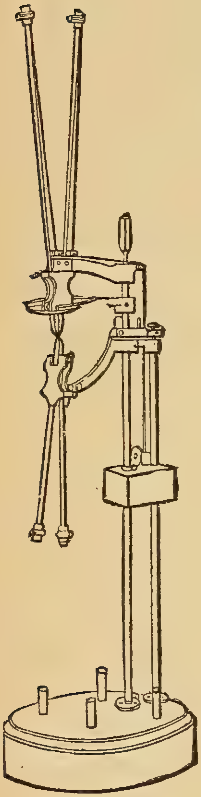
If friction and resistance of air be deducted from the gross power absorbed, and the power actually absorbed in the production of current only considered, as is usual in determining the efficiency of dynamo-electric machines,

$$\frac{11·285}{13·78} = ·8189;$$

or 81·89 per cent. of the absorbed power is converted into current. As before, 84 per cent. of this current appearing in the arcs, $81·89 \times ·84 = 68·72$ per cent. of the entire power is absorbed in the production of current, present as heat and light in the sixteen arcs.

In Rapieff's lamp, Figs. 100 and 101, the vertical arrangement of the carbons is maintained, but instead of one positive or negative carbon, each carbon is duplicated. The duplicate parts are placed relatively to each other in the form of a V, and touch only at their ends. Each carbon passes through a holder with a small guiding wheel, at about 2 in. from the end. The current enters the carbon at this point, and is not carried through the whole length of the carbon. The resistance is thus maintained uniform. The electric arc is produced between the upper and lower pairs of carbons; and the position of the carbons is determined by the intersection of the two axes of the carbon rods, so that a constant length of arc is necessarily consequent, whatever may be the rate and irregularity of consumption. Each carbon rod moves freely between guides in the direction of its length, and is drawn through these guides by a cord and weight, to form the apex of the V with the other rod. The motion is stopped by the two carbons impinging against each other. The plane of the upper pair of carbons is at right angles to that of the lower pair. Fig. 100 is of a lamp thus constructed.

100



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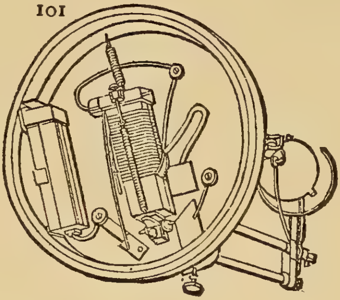

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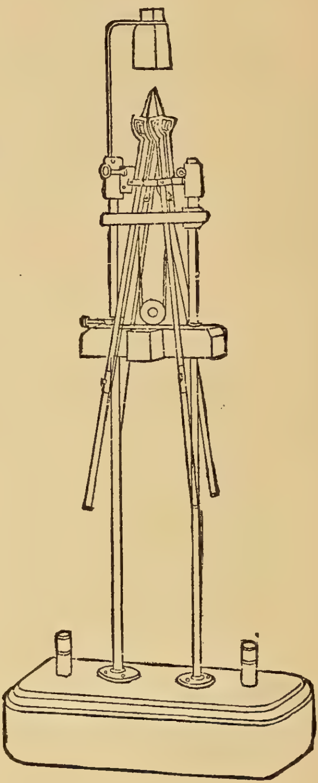

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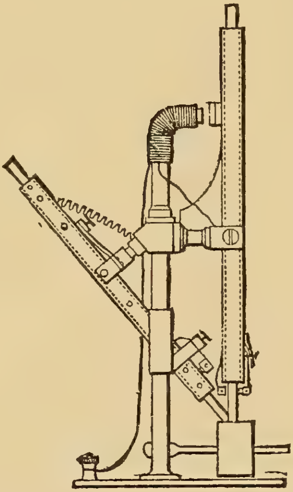

When the current is interrupted the lower pair of carbons is kept in contact with the upper pair, by the action of a light spiral spring placed in the base of the lamp, and acting through a vertical rod passing up one of the pillars. To the free end of each of the carbon rods is attached, by a screw clip, a silk thread, which, passing over the pulleys, is attached to a weight sliding up and down the two pillars. This weight tends to draw the carbon pairs together. The current established, the lower pair of carbons is drawn away from the upper by the action of the electro-magnet, in the base of the lamp, Fig. 101. The electro-magnet is in two parts, one of which is fixed, while the other is hinged, so that the passage of the current through the coils causes the hinged magnet to approach the fixed one, lift the sliding rod, and separate the carbons. The base of the lamp contains also an automatic shunt, which throws into the circuit a resistance equivalent to that of the arc, when the lamp is extinguished. When the current ceases in the coils of the electro-magnet, the armature is released, and falls back against a fixed contact piece, introducing into the circuit an artificial resistance of carbon.

Fig. 102 is of another form of Rapieff's lamp in which the two pairs of carbons are arranged side by side, instead of vertically above each other. Above the arc is a cake of lime, which serves to reflect the rays, as well as to maintain the illuminating power during momentary cessation of the current. These lamps can be employed with currents of single or alternate direction. In one instance, the pairs of carbons are equally consumed; in the other, the positive carbons have to be made twice as long as the negative carbons; and in either the point of intersection of the axis of the carbons, and consequently of the length of the arc, must remain constant. Six of these lamps have been worked on a single circuit, but no data are available as to the power absorbed for light produced.

Hedge's lamp, Fig. 103, somewhat similar in form to Staite and Edwards', differs in that the voltaic arc is automatically adjusted as to length. The carbons are free to slide in tubes or guides. The two electrodes thus arranged meet at an angle on a circular block of refractory material, such as lime. When the circuit is established, the arc is caused, by the separation of the two carbon points by an electro-magnet placed in the circuit of the lamp, and shown attached to one of the guides. The block of lime is made to revolve either by gravitation of the carbon, or preferably by a small motor, in order to remove the ash of the carbon. As the lime block becomes intensely heated the light is maintained steady.

Lontin has introduced a form of lamp in which the action of gravity is dispensed with, allowing of any length of carbon being employed. Clockwork or an electro-motor causes a bar, running parallel with the carbons, to revolve. The motion is imparted by bevelled wheels to others which cause the carbon carriers to revolve, and to carry the carbons, arranged horizontally, gradually forward. The carriers hold the carbons about 2 in. from the end of the carbon point, reducing the resistance to that due to this length of carbon, instead of giving that of the whole length as in many systems.

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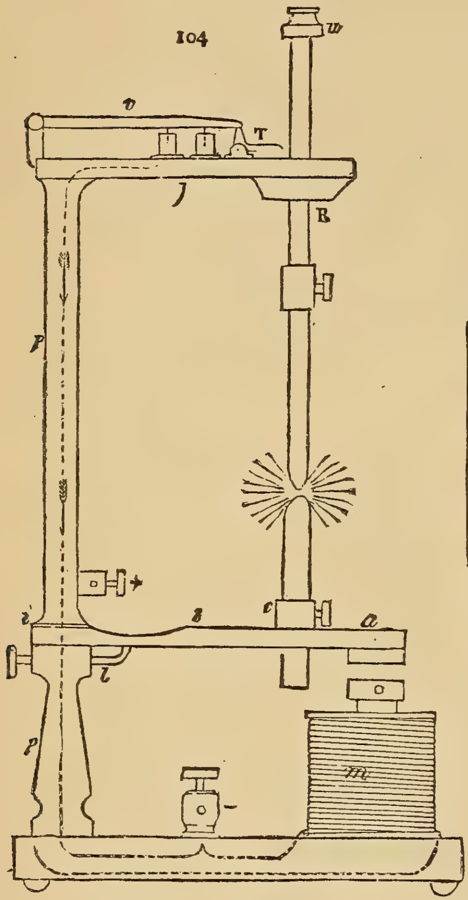

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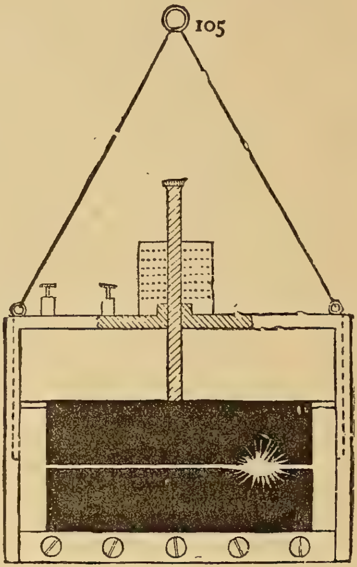

Lontin's original lamp is a modification of that of Serrin, and consists in substituting for the electro-magnet a metallic bar, so arranged that its expansion, under the heat produced by the passage of the current through it, causes the separation of the carbon points. In another form, Lontin inverts the action of the Serrin lamp, causing the current to be interrupted where, in the ordinary form, it was continuous.

In Thomson and Houston's system, one or both of the carbon electrodes are caused to vibrate. The electrodes are placed at such a distance apart that, in their motion towards each other, they touch. These vibrations are made at such a rate that the effect of the light produced is continuous. A flexible bar, *b*, of metal, Fig. 104, is firmly attached to a pillar *p*, and, at the other, bears an iron armature, *a*, placed opposite the adjustable pole-piece of the electro-magnet *m*. A metal collar *c* supports the negative electrode, and an arm *j* the positive electrode. The pillar *p* is divided by insulation at *i*, into two sections, the upper one of which conveys the current from the positive terminal to the arm *j* and the rod R. The magnet *m* is placed in the circuit. When the current circulates, the armature *a* is attracted, and the electrodes separated; on the weakening of the current the elasticity of the rod *b* again restores contact During the movement of the negative electrode, since it is caused to occur many times a second, the positive electrode, though partially free to fall, cannot follow the rapid motions of the negative electrode, and therefore does not rest in permanent contact with it. The slow fall of the positive electrode is ensured by proportioning its weight. The rapidity of movement of the negative carbon may be controlled by means of the rigid bar *l*, which regulates the length of the vibrating arm.

In order to prevent a break from occurring in the circuit, when the electrodes are consumed, a button, *u*, is attached to the upper extremity of the rod R, at such a distance that when the carbons are consumed as much as is deemed desirable, it comes into contact with a tripping lever T, which allows two conducting plugs, attached to the bar *b*, to fall into mercury cups, attached to the positive and negative terminals by a direct wire.

The object of the vibration of the electrodes in this system is to aid illumination by the extra spark, as well as to help the formation of a voltaic arc that is practically continuous.

In the Wallace-Farmer lamp no carbon rods are employed; the carbons take the form of two plates, Fig. 105, each about 9 in. long and 3 in. broad, the upper or positive plate being double the thickness of the lower plate. The lower plate is fixed, but the upper plate slides in a grooved frame. Above the frame an electro-magnetic apparatus provides for the separation and contact of the plates, as the strength of the current may regulate. The arc, always seeking the position of least resistance, shifts from point to point between the plates, as these are consumed. The plates are sufficiently large to last for a hundred hours, and six of these lamps can be burnt in a single circuit.

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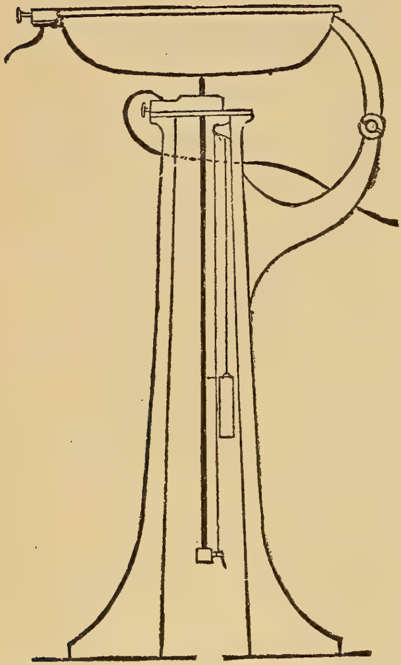

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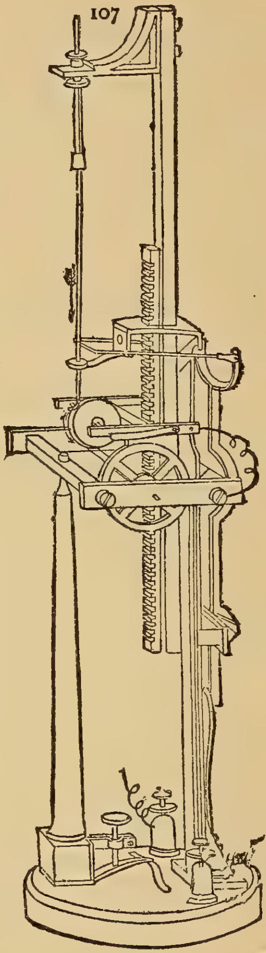

Fig. 106 is of Werdermann's lamp. A block of carbon is connected to the negative pole of the electric source, the positive pole being connected to the carbon rod, which is thin, but of any required length. The carbon rod is kept in contact with the block by means of a weight and a cord passing over a pulley. The lamps are arranged in circuit in multiple arc. It might appear that this is a lamp in which illumination is due to incandescence of the carbon, but M. Werdermann contends that repulsion between the carbon rod and disc gives a small arc, which adds greatly to the brilliancy of the light.

Fig. 107 is of Reynier's lamp, different in construction, but similar in principle. The carbon rod impinges on a carbon wheel, the revolution of which is maintained either from the rackwork of the descending carbon holder, or from the tangential component of the pressure of the carbon pencil on the circumference of the disc. A brake is employed for retarding the fall of the carbon rod, and is operated entirely through the rod. The contact wheel is carried by a lever; the pressure exerted by the carbon on the wheel causes a shoe to press on the face of a wheel, which is revolved by means of the weight of the heavy rod, through its rack and pinion. Accordingly, as the point of the luminous conductor passes more or less heavily on the disc, the brake will proportionately retard the descent of the heavy carbon holder. Contact is established, not at the end of the carbon holder, but by a lateral spring contact, about ¼ in. from where the carbon presses on the wheel.

André's lamp is suitable for lighting mines, but may be applied to other purposes. In Figs. 108 to 110 *a a* are four carbon rods, *b b* four copper discs, each having a small piece of iridio-platinum let into the point upon the rim touched by the rods. The carbon rods *a* are enclosed in tubes A, sliding easily, and are lightly pressed down by small loose weights. *d* is an intervening button or guide piece in which the upper end of the carbon is inserted. By means of a commutator, one of the carbons only is kept in a state of incandescence at a time, and when that one is inoperative, the next carbon is automatically rendered incandescent. To prevent waste of the carbons, and as regards mines also to prevent fire-damp explosions, the carbon rods *a* are enclosed in a glass cylinder C. As the oxygen is consumed by the combustion of the carbon, the rate of wasting of the latter is gradually lessened, and in the course of, say, half an hour, the enclosed atmosphere will consist of only nitrogen and carbonic acid.

The discs *b* are connected together by a central bar *e*, and the two outer discs *b* are, by screws *f*, pivoted eccentrically to the bracket F. The negative pole is by the bracket F connected to the discs *b*. The enclosing tubes A are for this purpose connected to the positive pole through the standards D, and have each at the lower end a lever *g*, the outer and heavier end of which serves to press the carbon against the lower part of the tube A. The part of the lever coming against the carbon is hollowed out so as to partly embrace it, to produce good electrical contact, and cause the current to enter the carbon from both sides. The carbon in burning away leaves a siliceous deposit on the metal disc on which it rests. This deposit causes occasional sudden extinction of the light by interrupting the current; another cause of extinction is the softening to a pasty consistency of the lower part of the carbon, causing this part to adhere to the tube at the place of contact. To obviate these disadvantages, a turning action is imparted to the disc *b*. E is an electro-magnetic core, with coils round it connected to the bracket F and to one of the outer rods, for the return of the current. The armature G of this electro-magnet is fixed to the central bar *e* of the discs *b*; H is a stopper for preventing the armature G from receding too far from the core E; K is a stopper on the opposite side for preventing the armature from approaching too near to the electro-magnet, and which may also be provided with a coil, connected to the rod I for the return current, but shorter than the coil on the core E; thus producing less resistance to the

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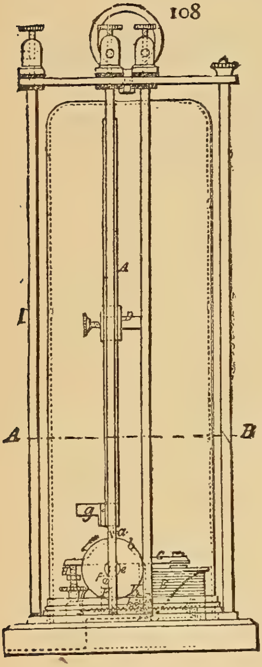

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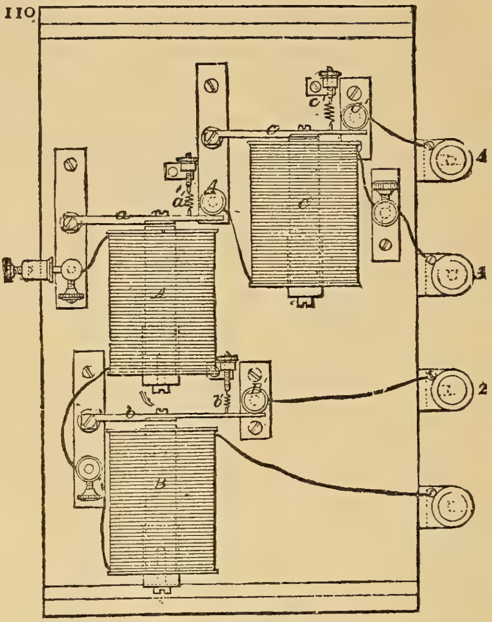

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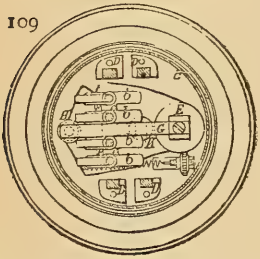


current, and causing a small part only to act on the electro-magnet after the armature has been attracted.

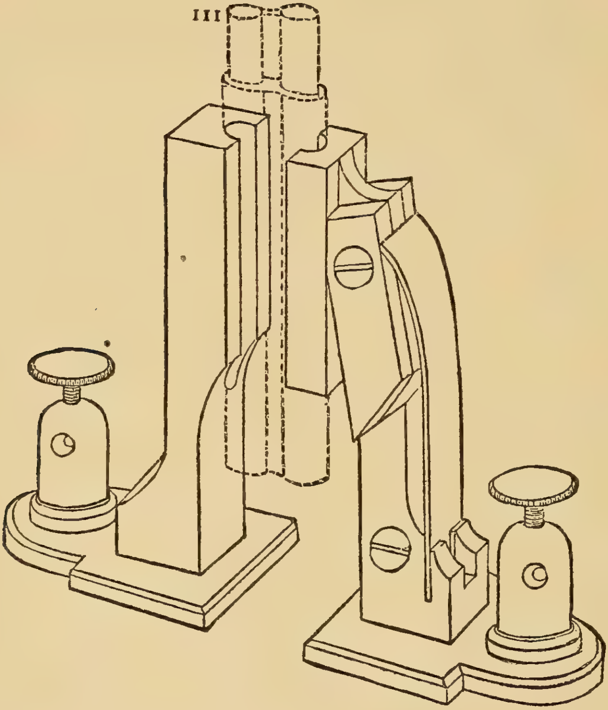
When the current passes through the coils of the electro-magnet, the armature is attracted, and the carbons are pulled over into good contact with the lower ends of the tubes. The larger portion of the current is shunted through the stop K to the terminal rod I, in order to lessen the attractive force of the electro-magnet, and to diminish the resistance. In case the current is interrupted at the place of incandescence, the armature G is let go from the position shown, and a spring *h* then turns the eccentrically mounted discs slightly in the direction of the arrow, causing the disc to rise a little, and the carbon, if stuck, to be released, and any siliceous deposit on the discs pushed away by the carbon point. When the circuit has been restored, the armature will be attracted again, and the discs turned into their former position.

The commutator, Fig. 110, combines two or more electro-magnets A, B, and C, with their respective armatures *a*, *b*, *c*, in such a manner that, when the connection to one of the carbons in the lamp is interrupted, the corresponding electro-magnet releases its armature, and this then serves to throw the current through the electro-magnet corresponding to the next carbon, causing it to light. The number of electro-magnets is one less than the number of carbons.

Each armature when not attracted forms contact with a pillar A′, B′, C′, respectively. Supposing there are four carbons, one of which only is to be alight at a time, the current passing first through the coils of an electro-magnet A, placed between two other electro-magnets B and C; the armature *a* of the middle magnet A being attracted, will be drawn away from a contact A′ connected to the coil on the top magnet C, and the wire connection from the middle magnet A to the coil of the bottom magnet B, will cause the armature *b* of this magnet to be attracted, and drawn away from the contact B′ connected with the binding screw 2 for the second carbon.

The coil on the bottom magnet B is connected to the terminal binding screw 1 for the first bottom carbon. If this carbon becomes inoperative, the armature *b* for the bottom magnet B will by its spring *b′* be pulled over against the contact B′ in connection with the terminal binding screw 2 connected with the second carbon, and no current will pass through the bottom or top electro-magnet coils B and C respectively. When the second carbon becomes inoperative, the armature *a* of the middle magnet A is let go and comes against the contact A′. The armature *c* of the top magnet C is then attracted, and the current passes through the armature *a* of the middle magnet A′ through the coils of the top magnet C and to the terminal or binding screw 3 for the third carbon, and so on.

P. Jablochkoff's electric candle consists of two cylindrical carbon rods, about $\frac{3}{16}$ in. diameter, each weighing about 8 grains an inch. These rods, varying from 6½ in. to 10 in. in length, are placed vertically side by side, with about $\frac{3}{16}$ in. space between them, which is filled with plaster of Paris. This combination constitutes a candle, and it is inserted in a holder, Fig. 111, and there held merely by a spring clip. To complete the circuit and to start the lighting of the candle, there is laid horizontally, from top to top of the carbon rods, a small piece of graphite or lead from a drawing pencil. When once lighted, combustion is maintained by fusion of the plaster of Paris, and the candle, if once extinguished, cannot be relighted. The fusion of the insulating material is found to absorb about 30 per cent. of the electric current. The relative consumption of car-



111

bon on this system is shown by the following table, where the first light is obtained from a constant current system, and the second from a candle:—

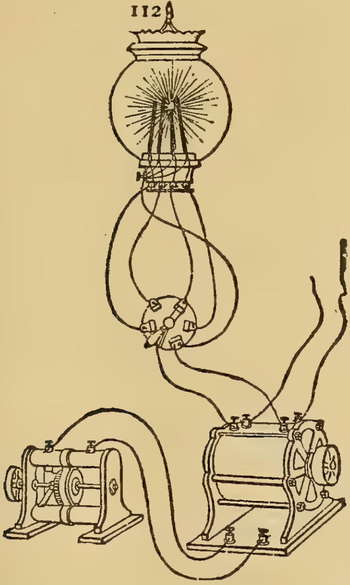
TABLE VII.

Light in Candles.	Length consumed in Inches an Hour.	Approximate Weight in Grains.	Grains of Carbon an Hour for Candle-power of Light.
705	3·15	20·3	0·106
760	3·0	7.5	0·060

But with a light of 1230 candle-power from a continuous current system, only ·062 grain of carbon for each candle-power of light has been consumed an hour, showing the advantages of the different systems respectively.

Fig. 112 represents the arrangement of the lamps and machines upon the Jablochkoff-Gramme system, usually employed with the Jablochkoff candle. To effect the ignition of a fresh candle, an automatic arrangement has been devised, which consists of a pivoted bent lever pressing by a spring against the side of the candle. This lever at its other end makes contact with the connection of a second candle, when released by the consumption of the first.

112



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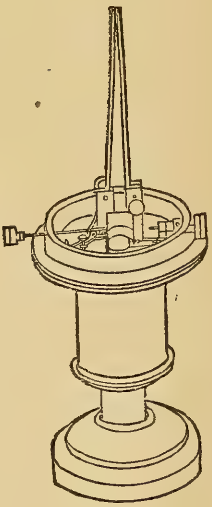

The objections to the Jablochkoff candle on the score of difficulty in relighting, and loss of current consumed in the fusion of the insulating material, led De Meritens to place between the two carbon rods, but not in contact with them, a third rod, of about half the diameter, instead of the insulating substance. The electric arc plays from the outer carbons to the intermediate rod, which is consumed. The arc thus divided has less probability of total extinction, and requires lower expenditure of power to produce, as it has less distance to leap.

Rapieff's candle lamp, Fig. 113, is a return to mechanical aid. There is no insulating material between the carbon rods, and their distance apart is regulated by a screw. The holder of one of the carbons is connected to the armature of an electro-magnet concealed in the stand. When no current is passing, the upper ends of the rods are brought into contact by a spring, attached to the armature of the movable carbon. When a current passes the armature is attracted, and the carbons are separated to the distance necessary to produce the arc. Upon interruption of the current the armature is released, and the circuit again completed.

H. Wilde's candle lamp is similar in principle to the preceding, but includes an automatic switch, which by means of a spring brings successively into play a series of lamps as the consumption regulates, the temporary cessation of current releasing a table upon which the lamps are fixed. This table revolves, and brings into contact, with the conductors, another lamp.

The production of the electric light by the incandescence of a badly-conducting substance, has been regarded by electricians as presenting the most simple and advantageous system. But there are difficulties attending the plan not apparent at first sight, and the chief is choice of the material to be raised to incandescence. Metals are subject, even platinum and iridium, to accidental fusion by sudden increase of current; carbon, although infusible, oxidizes when heated in contact with air, and has to be renewed. Means of removing the air, and maintaining an atmosphere free from oxygen, have not been carried out in practice. Platinized asbestos, finely divided oxides, plumbago mixed with kaolin, have been proposed, but these substances have not hitherto given satisfactory results, becoming brittle under the influence of the intense heat, or otherwise suffering change after short periods of use.

King, in 1845, first proposed the use of a carbon rod, which was supported between two blocks of carbon, in a glass vessel from which the air had been exhausted. Lodyguine, in 1873, re-introduced the system, diminishing the section of the carbon at the luminous point.

Konn's lamp contained two carbons, the second being brought into use when the first was consumed, by the simple expedient that consumption of the first allowed a trip hammer to fall into contact with the second.

In Bouliguine's incandescent lamp, the carbon rod was forced upwards by a counterweight into the clip-jaws of an upper holder. When the current ceased, an electro-magnet released these jaws, allowing the broken carbon to fall out, and its place to be supplied with a new length of the rod, under the upward action of the counterweight.

None of these lamps are now in practical use; but a modification of the system has been adopted in the Sawyer-Man burner in use in America. In this burner the incandescent portion consists of hard wood-charcoal quenched in oil, by which a very dense steel-like carbon is obtained, through the condensation of the carbonized oil in the pores of the heated charcoal.

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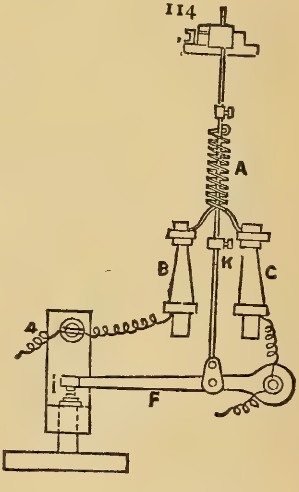


Fig. 114 is of T. A. Edison's incandescent lamp, in which fusion of the platinum coil, used as the bad conductor, is prevented, by shunting the current when too intense, by the expansion of the coil itself, or by its radiating effect. The spiral A is connected to the supports B and C, and is surrounded by a glass cylinder. K is an expansion bar, fixed firmly above, and attached also to a lever F, which can connect electrically the two conducting supports B C. The rod K will expand in proportion to the heat of the coil, and, if the heat becomes too high, injury to the coil is prevented by the expansion of the rod K causing the lever F to close the circuit at I, and short circuit the current from the coil A. Immediately the rod K cools, the short circuit is withdrawn.

Whether the use of carbon or of platinum is the more economical has yet to be determined. Ayrton has shown that light should be maintained in a carbon rod by a minimum electro-motive force of about half a Daniell's cell, whilst one-third cell only is required for platinum. But the same quantity of caloric raises the temperature of a small bar of carbon, to a degree nearly twice that attained by a platinum wire of the same dimensions. The resistance of the carbon is about 250 times that of the metal, so that a carbon rod may be fifteen times thicker than a platinum rod to give the same result.

The maximum light attainable in practice in any system of incandescent burners appears to be of 250 candle-power. Beyond the temperature necessary to produce this amount of light, the fusion of the siliceous impurities in the carbon affords much difficulty. Economically considered, when the light passes that of 100 candles, the system of incandescence rapidly becomes disadvantageous, as compared with that of the arc, whilst the use of the arc becomes cheaper as the light-centre is more intense.

Ayrton has also remarked, that the insulating material in the Jablochkoff electric candle owes its imperfect success to the fact, that when it became heated, the resisting power was greatly diminished, so that there was a great loss of current through leakage from one carbon to the other. Wilde shows that the employment of this insulating substance is needless, for when he used a Jablochkoff candle with only air between the carbons, the electric current passed from carbon to carbon, at the top, and not along the whole length; and further, if the arc were started, by means of a wire placed and withdrawn, at any other part of the parallel carbons than at the top, it immediately proceeded to the top, at which place alone it continued to shine.

Wilde attributed this curious effect to the convective action of the heated air, considering, in fact, that the air was blown up to the top of the carbons, very much as a lighted piece of paper is blown up a chimney. Ayrton has shown, that while convection of the air greatly assisted the action, the fact that the arc would travel downwards if the lamp were inverted and lighted at the now upper part of the carbons, near the metal carbon holders, proved that the cause of the motion was not only quite distinct from air convection, but was sufficiently strong to overcome such convection, and that the explanation was, that this motion was caused by the repulsive action between the currents in the carbons, and that constituting the arc itself, in accordance with Ampère's law, concerning the action of a current on another at right angles to it.

With considerable experience in the practical manipulation of most of the systems for electric lighting, P. Higgs has found that some systems presented considerable, and that others of more delicacy of adjustment, necessary to practical employment, gave insuperable, difficulties. These difficulties arise chiefly from three causes: that the carbons are not homogeneous, the current inconstant from variations in the resistance of the circuit, and generally from the want of promptness in the mechanism of the lamp to respond to the variations so caused. Most of these electrical apparatus have been devised either with too broad or imperfect views, or with only special application. In the case of carbon holders carrying 7 or 8 in. of carbon to be consumed, the resistance of this amount of carbon, if the material is not of the highest quality, is likely to exceed that of the arc and lamp itself; and this resistance, constantly varying, has to be compensated for by the mechanism of the lamp. This imperfection has been avoided by Rapieff, Werdermann, and Lontin. Some inventors have recognized it, and have proposed, as a remedy, to electrotype the carbon rods with a conducting metal; but the practical electro-metallurgist is cognisant of the difficulty of obtaining regularity in such deposits of metal, and the expense of the coating is, besides, to be taken into account. In each case the long lengths of carbon become heated, and with coppered carbons, the mass of metal is insufficient to carry away the heat generated by the passage of the current.

The first aim of the electrician who has to maintain an efficient and steady light is, undoubtedly, to obtain as constant a current as it is possible with either a battery or an electric machine. Battery currents vary, as a rule, very gradually; currents produced by mechanical motion are subject to the irregularities of that motion. The slip of belting, the beats due to want of balance in the flywheel, are represented in the electric current with too much fidelity for the comfort of the electric-light engineer. But with care these causes of irregularity can be avoided, and the needle of even a delicate galvanometer, interposed in the circuit of a well-set machine, driven by a steady motor, will remain fixed at a degree of deflection representing the current strength.

But this steadiness vanishes immediately the electric lamp is introduced into the circuit, so far as the light is concerned. This occurs partly because the lamp is, as regards the light it emits, a much more delicate current measurer than the galvanometer. The light power from the carbons of an electric lamp depends not directly upon the current strength, but increases or decreases far more than proportionally.

The heat produced by the current varies as the square of the current strength, and the light varies in some such ratio as regards the heat. Thus, a variation in current intensity, measured by the number 2, may be considered in illustration as causing a variation of 16 in the light intensity. It is, therefore, needful to avoid causes of variation in the lamp, for these, it is evident, will have similar effect upon the light intensity to those arising from the machine. Indeed, variations introduced by the lamp cause variations to occur from the machine, unless the latter be extremely well governed.

A decrease of resistance in the circuit causes more work to be thrown upon the motor, and conversely. If the motor, in consequence, momentarily slackens or increases speed, there must elapse several moments before the same conditions, as existed before the disturbances, are again established, and the largest of these variations are certainly visible as variations in the light. That most of these variations are due to reaction from variations in the lamp itself, is proved by the superior steadiness of the light produced on the principle of incandescence alone. This fact has caused many inventors to overlook the cost of the light produced merely by incandescence, and to avoid in their lamps the use of the voltaic arc with what appears to be its necessary attendant irregularity.

DYNAMO-ELECTRIC AND MAGNETO-ELECTRIC MACHINES.

A magneto-electric machine is a mechanism intended to create electric currents by the help of magnetism. The term magneto-electric is confined to those machines in which the magnetism is obtained from permanent magnets. When permanent magnets are replaced by electro-magnets, the term dynamo-electric is used. The term dynamo-electric is, of course, applicable to any form of machine, such as a frictional electric machine, by which work is converted into electricity, but custom has limited its use.

The same principle underlies the action of all magneto- and dynamo-electric machines, that the cutting of a line or field of magnetic force, by a closed wire circuit, induces in the wire an electric current. The direction of this current varies with the direction of motion and the polarity of the magnetic field.

If a bar magnet is introduced into a coil of insulated wire, an electric current appears in the wire, if the circuit is closed. Entry and withdrawal of the magnet induces currents opposite in direction. An electro-magnet may be substituted for the bar magnet with similar, but generally enhanced, effect. These facts are those utilized in the construction of dynamo- and magneto-electric machines.

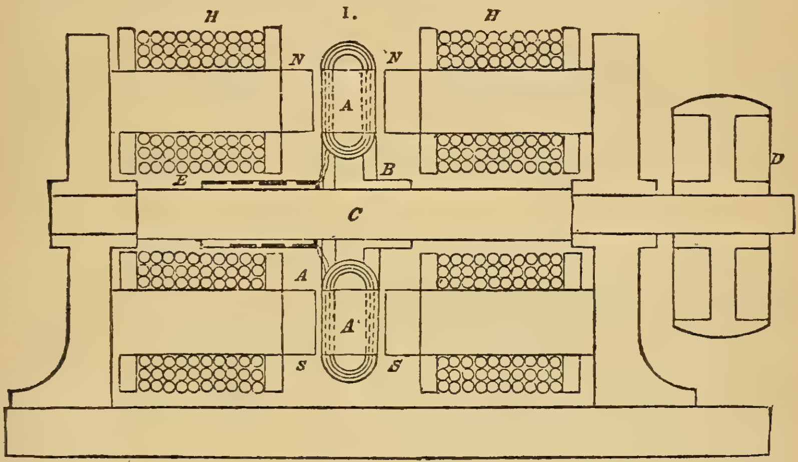
Pixii's machine, invented in 1832, consists of an electro-magnet attached to the upper part of a framework, and a magnet arranged to revolve rapidly before the electro-magnet, pole to pole. A handle and a pair of bevel wheels suffice to rotate the magnet. When movement is imparted to the magnet, its poles are made to pass successively before the poles of the electro-magnet. There is induced in the wire of the coils, at each half revolution, a current which passes into the conducting wires. This current is alternately direct and inverse, and for many applications must be caused to take one direction. This is effected by means of a commutator on the axis of rotation, upon which press springs in connection with the conducting wires. The commutator consists of two halves of a cylinder completely insulated one from another by a bad conductor. If each half cylinder be connected with one of the poles of a voltaic battery, when the cylinder is at rest, the friction springs are affected by a direct current; but when the cylinder rotates, the current collected by the friction springs will change direction. If the cylinder be put on the axle of a machine, so as to turn with it, and the one half cylinder be connected to one coil of the electro-magnet, and the second half cylinder to the other, the currents collected are always in the same direction, because the current in the electro-magnet changes its direction at the same instant that the friction springs change on the half cylinders.

Clarke's machine consists of a bundle of horse-shoe magnets. Before this bundle two bobbins are revolved, by means of a bevel wheel and small crown wheel mounted on the axle of the coils. The coils are wound on two cylinders of soft iron, connected together by the same metal. A commutator at the extremity of the axis redirects the currents.

A. N. Breguet's machine resembles Clarke's machine, but in the latter, however rapidly the currents are made, they are not absolutely continuous, whilst in the former, by modifying the rotating bobbins, there is obtained a perfectly continuous electrical current. A circular disc is mounted on a horizontal axis. Twelve bobbins are inserted in this disc. The bobbins are connected together as so many elements of a galvanic battery, and form one continuous length. The electrical condition of each bobbin, when in movement, may be inferred from Lenz' law, that an inverse current is induced when a conductor approaches a pole of a magnet, and a direct current when it is withdrawn from the pole. Suppose the whole armature of coils of wire to revolve from left to right, all the bobbins on the left will be traversed by a current in one direction, and all those on the right by a current opposite in direction, but equal in volume to the former. The apparatus may be compared to two distinct batteries, consisting of six elements each connected together for tension. To effect the union of the two batteries for quantity, two metallic springs are attached to two small uprights which are the terminals of the magneto machine. Twelve strips of copper are disposed radially, and to them are attached the two adjacent ends of each pair of bobbins. The metallic springs act as current-collectors; and as they are always in contact with several of the radial strips, they must always be traversed by electric currents. Hence the perfect continuity of the current developed by this machine, which is serviceable in cases requiring high tension but small quantity.

Figs. 1 to 4 are of the Brush dynamo-electric machine. The iron armature of this machine is in the form of a ring, and is attached to a hub. This hub is rigidly attached to the shaft C, which when driven by the pulley, causes the armature to revolve in its own plane. The armature is provided with grooves or depressions, in a direction at right angles with its magnetic axis or length. These grooves are wound full of insulated copper wire. The sections of wire thus formed are of any suitable number. The advantage of winding the wire on the armature depressions is twofold:—The projecting portion of the armature between the sections of wire may be made to revolve very close to the poles N N and S S of the magnets, from which the magnetic force is derived, thus utilizing the inductive force of the latter, to a much greater extent than is possible in the case of annular armatures entirely covered with wire, which cannot be brought very near the magnets. Owing to the exposure of a considerable portion of the armature to the atmosphere, the heat, which is always developed, by the rapidly succeeding magnetizations and demagnetizations of armatures in motion, is rapidly dissipated by radiation and convection. In the case of armatures entirely covered with wire, the escape of heat is very slow, so that they must be run at a comparatively low rate of speed to prevent injurious heating.

Diametrically opposite sections of the armature may have their first or last ends joined together, and their remaining ends connected with two segments of metal of the commutator cylinder, which is carried by the shaft, and is of insulating material. The two metal segments are placed diametrically opposite each other on the cylinder, and are each of a length less than half the circumference of the latter, thus exposing the insulating cylinder in two places diametrically opposite each other and alternating with the metal segments. The two segments S^3, and S^7, Fig. 3, corresponding to sections 3 and 7 of wire, hold a position on the cylinder, in advance of those of the preceding sections S^2 and S^6, to the same angular extent that the sections 3 and 7 in question are in advance of sections 2 and 6. In this arrangement the number of segments is equal to the number of sections, each segment being connected with but one section. The first and last ends of each section can, however, be attached to two diametrically opposite segments, the commutator cylinder in that case being constructed with double the number of segments as in the former case, thus making the number



of segments double the number of sections. Two metallic plates or brushes, insulated from each other, press lightly upon the cylinder, at opposite points, so selected that while each section of wire on the armature is passing from one neutral point to the other, the corresponding segments on the cylinder will be in contact with them. These plates or brushes collect the currents of electricity generated by the revolution of the armature, one being positive and the other negative. When the section of wire is passing the neutral points on the armature, the plates are in contact with the insulating material of the cylinder between the corresponding segments, thus cutting the section, which is at the time useless, out of the circuit altogether. The necessity of thus insulating each section from the plates during the time it is inactive, is obvious, otherwise the idle section would afford a passage for the current generated in the active sections.

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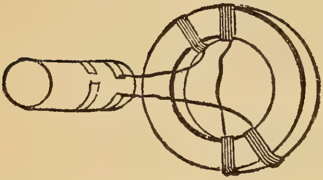

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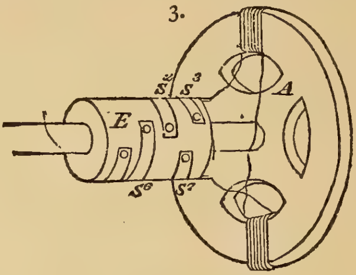

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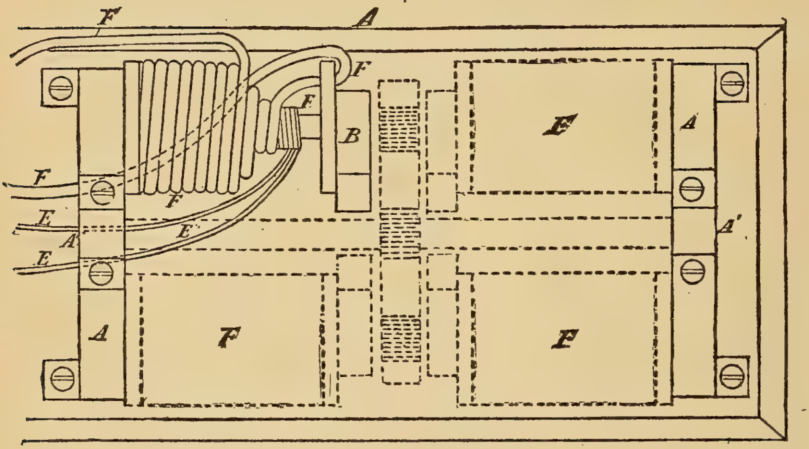

During the time a section or bobbin is passing from one neutral point of the armature to the next one, an electric impulse, constant in direction but varying in electro-motive force, is induced in it. This electro-motive force, starting from nothing at the neutral point, quickly increases to nearly its maximum, and remains almost constant until the section is near the next neutral point, when it rapidly falls to zero as the neutral point is reached.

The insulating spaces are made of such a length that each section or bobbin is cut out of the circuit, not only when it is at the neutral points, but also during the time when its electro-motive force is rising and falling at the beginning and end of an impulse.

If the insulating space is too short, so as to keep or bring a section in the circuit while its electro-motive force is low, then the current from the other sections, being of superior electro-motive force, will overcome this weak current, and discharge through this section. If the insulating spaces are a little longer than necessary, no material inconvenience results. A suitable length for practical purposes is easily determined experimentally. It is necessary to adjust the commutator cylinder on the revolving shaft of the machine, with special reference to the neutral points of the armature when in motion, in order that its insulating space may correspond to the neutral points. This adjustment is made as follows. The commutator cylinder having been placed approximately in its proper position, the machine is started, and the presence or absence of sparks at the points of contact between the plates and commutator cylinder is noted. If sparks occur, the commutator cylinder is turned slightly forward or backward on its axis until they disappear.

The presence of sparks, when the commutator is even slightly out of its proper position, is easily explained. If a break between a pair of segments and the plates occur while the corresponding section of wire on the apparatus is still active, a spark is produced by the interruption of the current, while if the break occurs too late, the section in question will have become neutral, and then commenced to conduct the current from the active sections, and the interruption of this passage causes a spark in this instance. If the commutator is much removed from its proper position in either direction, the sparks are so great as to very rapidly destroy both the commutator and the brushes, while the current from the machine is diminished.

When the first and last ends of each of two diametrically opposite sections are attached to two opposite segments, the intensity of the induced electric current will be that due to the length of wire in a single section only, while the quantity will be directly as the number of sections. By doubling the size of each bobbin, and diminishing their number one half, a current of double the intensity and one-half the quantity of the former will be obtained.

This effect can also be secured by connecting the first and last ends of the two opposite sections together, and joining the remaining ends to two opposite segments, Fig. 2. This arrangement of the cylinder with the segments may be replaced by another, in which the last end of one section, and the first end of the succeeding one, may be connected with a strip of metal attached to the cylinder, parallel with its axis, as in the Siemens and Gramme machines.

These metallic strips or conductors are equal in number to the sections of wire on the armature, and are insulated from each other. The plates press upon the cylinder, in this case, at points corresponding to the neutral points of the armature, thus being at right angles with their position in the first arrangement. This plan gives fair results, but is subject to a disadvantage from which the first is free. The difficulty is that the sections of wire, when at or near the neutral points of the armature, contribute little or no useful effect, but the current from the other sections must pass through these in order to reach the plates, thus experiencing a considerable and useless resistance; and, owing to the opposite directions of the currents through the active sections on opposite sides of the neutral points, these currents, by passing through the idle sections, tend strongly to produce consequent points in the armature where the neutral points should be, thus interfering with the distribution of the magnetism of the armature.

The electro-magnets H, are excited by the whole or a portion of the electric current derived from the revolving armature. The arrangement in which the magnetic poles are presented to the armature is such, that a very large proportion of the entire surface of the armature, is constantly presented to the poles of the magnets, thus securing uniformity of magnetization as well as maximum amount.

By diverting from external work a portion of the current of the machine, and using it, either alone or in connection with the rest of the current for working the field magnets, a permanent field may be obtained.

This plan is adaptable for electro-plating machines. If the external circuit be broken entirely, the magnetic field will in the former plan remain unimpaired, and in the latter remain sufficiently strong to effect the desired end.

The cores of the field magnets are wound with a quantity of a comparatively fine wire E, having a high resistance in comparison with that of the external circuit F, and the rest of the wire in the machine. The ends of this wire are so connected with other parts of the machine, that when the latter is running, a current of electricity constantly circulates in the wire, whether the external circuit be closed or not. The high resistance of this wire, prevents the passage through it of more than a small proportion of the whole current capable of being evolved by the machine. When this device, termed a teaser, is used in connection with field magnets, also wound with coarse wire, for the purpose of still further increasing the magnetic field, by employing the main current for this purpose, then the teaser may be so arranged, that the current which passes through it will also circulate in the coarse wire, thus increasing efficiency.

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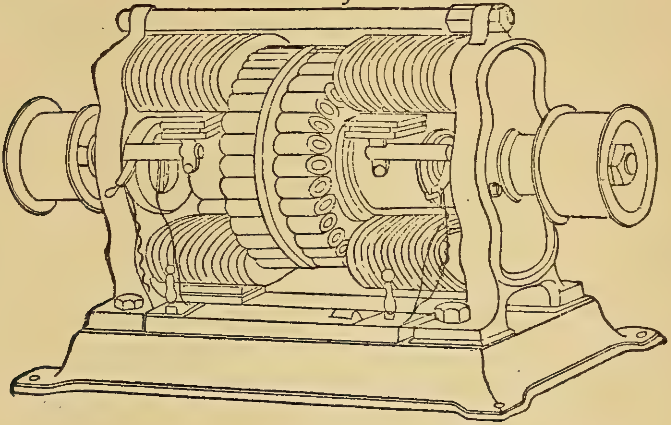

Fig. 5 is of the Wallace-Farmer machine. In this machine the magnetic field is produced by two horseshoe electro-magnets, with poles of opposite character, facing each other. Between the arms of the magnets, and passing through the uprights supporting them, is the shaft, carrying at its centre the rotating armature. This armature consists of a disc of cast iron, near the periphery of which, and at right angles to either face, are iron cores, wound with insulated wire, thus constituting a double series of coils. These coils, Figs. 6 and 7, being connected end to end, the loops so formed are connected in the same manner, and to a commutator of similar construction to that of Gramme. As the armature rotates, the cores pass between the opposed north and south poles of the field magnets, and the current generated depends on the change of polarity of the cores. This constitutes a double machine, each series of coils, with its commutator, being capable of use independently of the other; but in practice the electrical connections are so made, that the currents generated in the two series of armature coils, pass through the field magnet coils, and are joined in one external circuit.

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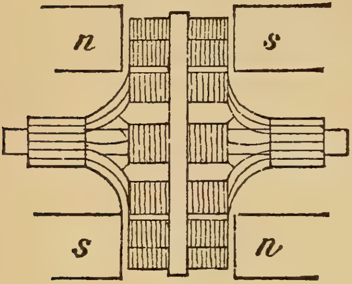

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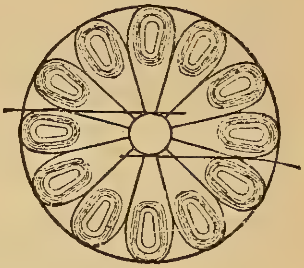

This armature exposes a large uncovered surface of iron to the cooling effect of the atmosphere, but its external form gives great resistance to rotation. In the Wallace-Farmer machine there is considerable heating of the armature, the temperature being sufficiently high to melt sealing wax.

Siemens and Halske's machine, of 1854, consists of a longitudinal coil, the iron of which is cylindrical in form, hollowed out parallel to its axis in two large and deep recesses, so that its transverse section resembles an I. The copper wire, insulated, is wound in the recesses parallel to the axis of the cylinder, and, with part of the iron left uncovered, constitutes a complete cylinder. One end of the wire is soldered to the metallic axis of the cylinder, and the other to a metal ring insulated on the extremity of its axis. The armatures of the magnet embrace the coil very closely, just allowing its rotation. The coil acts as the iron keeper generally furnished to magnets to prevent loss of power.

The Alliance machine, invented by Nollet and Van Malderen, is constructed with a number of bronze plates each carrying at its circumference 16 coils. These plates are mounted on a horizontal axle actuated by a motor through a belt, and revolve between eight series of compound magnets, set radially round the axis, and supported parallel to the plane of the plates by a special framework. As each magnet has two poles, one series presents 16 poles regularly distanced. There are an equal number of poles and coils, so that when one coil is facing a pole, the 16 others are also facing poles. These machines have four or six plates corresponding to 64 coils and 40 permanent magnets, and 96 coils and 56 permanent magnets respectively. One of the poles for the total current is attached to the axle, which is in communication with the frame by means of the bearings; the other pole terminates in a ring concentric to the axle and insulated from it. The current changes its direction every time a bobbin passes before the magnet poles. As there are 16 magnet poles, there are 16 changes a revolution, and as the machine makes 400 revolutions a minute, there will be at least 100 changes of direction a second.

At every change of polarity the intensity of the current should pass zero. Thus 100 times a second the spark ceases to play between the two carbons in an electric lamp, but the light does not appear discontinuous. This is owing to the persistence of light on the retina, also that the true voltaic arc only produces a fraction of the electric light, the remainder being due to the incandescence of the carbons. The tension of the current is insufficient to cause the spark to play to the distance between the cold carbons, but when these are raised to incandescence by the passage of the current, the surrounding atmosphere becomes better conducting, by the elevation of temperature and the presence of carbonaceous particles; the duration of the interruptions being very short, the properties of the atmosphere surrounding the carbon have not time to become sensibly modified, and the current recommences to pass.

In Holmes' magneto-electric machine for the production of light, introduced in 1869, Fig. 8, instead of the coils revolving before the magnets, the magnets revolve before the coils. Part of the current produced is employed to magnetize the electro-magnets; and the coils can give several independent circuits, and produce several independent lights in each circuit.

Wilde's machine consists of two Siemens' apparatus superposed and of unequal dimensions, with the modification that in the larger the magnet is replaced by a powerful electro-magnet. The upper and smaller machine is intended to magnetize the electro-magnet, and is termed the exciting machine. A longitudinal bobbin revolves between the two arms of the magnet, developing alternating currents, which are redirected by a commutator, and led to the electro-magnets by two terminals. Beneath is a large electro-magnet, the two branches of which are constructed of plates of sheet iron; and for the elbow of the horseshoe is substituted an iron plate carrying the exciter. The poles of this electro-magnet are masses of iron separated by a copper plate, and form a cylindrical cavity in which revolves the second Siemens' bobbin. This part of the apparatus is called the generator. The two bobbins are similar, but the diameter of the larger is three times that of the other. The exterior

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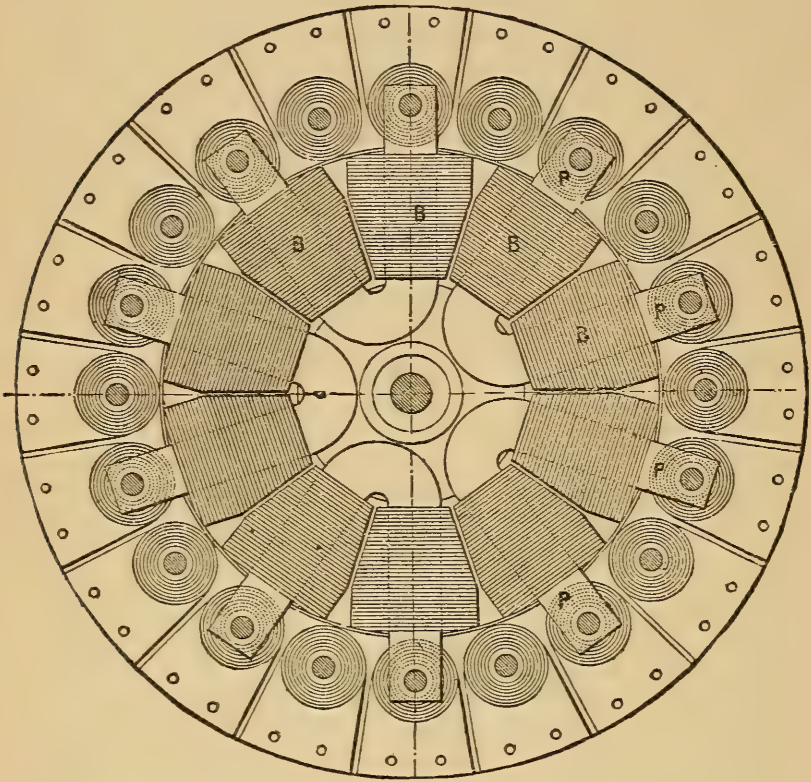

conducting wires are attached to its poles. The insulated copper wires which cover the branches of the large electro magnet are carried to terminals of the exciter. By the aid of two driving belts and a motor the two bobbins are caused to revolve, the smaller with a velocity of 2400 revolutions a minute, the larger with a velocity of 1500 revolutions a minute. The currents induced in the exciter maintain the larger electro-magnet strongly magnetized, and the currents induced in the generator are utilized in exterior work. Their intensity is greater than the currents from the exciter.

Ladd's machine consists of two parallel electro-magnets; at the extremities of these are placed two Siemens' bobbins of different sizes. The small bobbin excites the electro-magnets, and these react on the large bobbin which furnishes the working current. The wires from the electro-magnets are so connected that the contrary poles will be in relation when a single current passes. The free ends of these wires are carried to terminals, where they receive the currents from the small bobbin. Ladd's machine is also based upon the principle of mutual accumulation, discovered by Wheatstone, in which the exciting electro-magnets are included in the main circuit, and by reciprocal action induce currents of great strength in the revolving portion of the machine, whilst themselves fed from this revolving portion.

Trouvé's machine is composed of two or more electro-magnets in permanent magnetic contact, and participation in a rotary movement, like the trains of a rolling mill. The magnetic and electric circuits are both closed. The exits and entrances of the currents are made through the hollow axles, which admit in the centre the insulated conductors. Figs. 9 and 10 represent front and side views of this machine. It consists of a strong, straight electro-magnet, influencing a series of straight electro-magnets, forming a circular bundle. The whole system is set in rotary motion by the large electro-magnet, which also serves as a fly-wheel. The machine gives either reciprocal or continuous currents according to the arrangement of the commutator. It is either magneto- or dynamo-electric according to the employment of permanent or electro-magnets.

If the motion is as indicated by the arrow, all the electro-magnets, *d e f g*, placed at the left of the perpendicular, passing by the centre or axis, approach the large electro-magnet, which affects them, and generates in their respective bobbins positive currents; all the electro-magnets on the right of the perpendicular *h i j k*, receding from the great electro-magnet, are influenced by negative currents. A special commutator collects these currents, either to use them in quantity or in derivation, or to give them in tension.

Fig. 11 represents a Gramme machine arranged on this principle.

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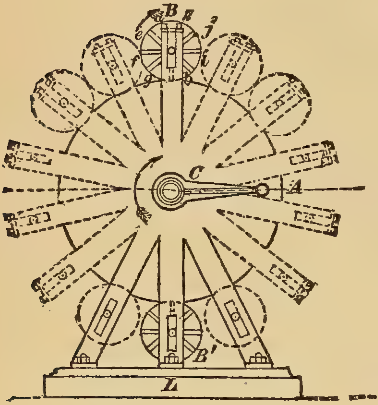

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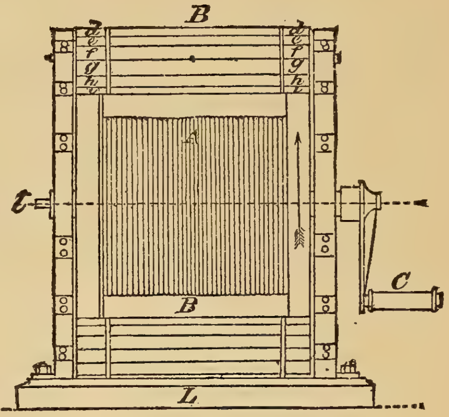
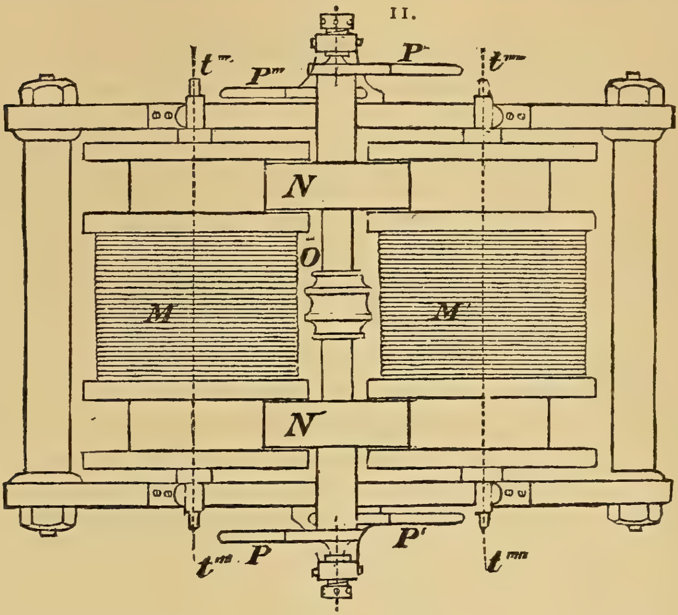


M M′ are two electro-magnets in permanent contact, by their opposite poles, with the discs N N′, thus forming a single magnet, for which one of the discs serves as a shank, and the other as an armature, constituting a completely closed magnetic circuit. Fig. 12 represents in section one of the two discs N N′, which are mounted on the common axle O. When they are set in motion, they communicate a rotary motion to the two electro-magnets, which influence them continually and thus generate currents in the series of bobbins which form the discs. The contact becomes more complete between M M′ and N N′, in proportion as the currents are stronger.

Rapieff's machine consists of several ring-shaped inductors A A A, Fig. 13, and several armatures of the same shape and arrangement, B B B are disposed alternately side by side in planes normal to their common axis, the spaces between them being rendered as small as possible. The armatures B B B are fitted on a common shaft, wherewith they are caused to rotate, while the inductors A A A being secured on a frame or stand, remain fixed; or inversely. The number or size of both inductors and armatures depends upon the special purpose for which they are employed; the induction being produced in this case from both sides of each armature, it is termed two-sided induction.

To illustrate the principle of Gramme's machine, Fig. 14 is of a magnetized bar A B. When a conducting helix, in reciprocal movement, is brought towards the bar from its position at X, an induced current is produced. The current is in the same direction while the helix passes the middle M of the bar A B, until it leaves the opposite pole B.

11.



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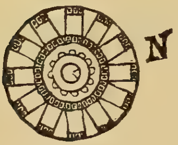

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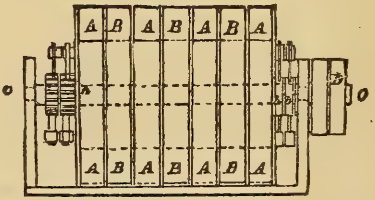

In the entire course of the helix on to and from the magnet, two distinct periods are to be distinguished; in the first half of the movement the current is direct, and in the second it is inverted. If, instead of moving from left to right, the movement is from right to left, everything occurs as before, with the exception that the currents are opposite. If two magnets, A B and B′ A′, Fig. 15, be placed end to end in contact by poles of the same name, B B′, the whole forms a single magnet with a consequent point at the centre. If

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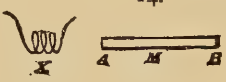

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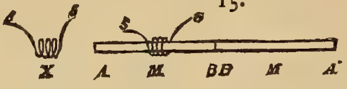

the helix is moved with relation to this system, it is traversed by a positive current during the first movement between A and B; by a negative current in the second, from B to B′; again, by a negative current in the third from B′ to A′; and finally by a positive current when leaving A′.

Replacing the straight magnets by two semicircular magnets, Fig. 16, put end to end, the poles of the same name together, there occur the two poles A A′, B B′, and the results are the same as the preceding, M M′ being the two neutral points.

The essential part of the Gramme machine is a soft iron ring, furnished with an insulated copper helix, wound on the whole length of the iron. The extremities are soldered together so as to form a continuous wire without issuing or re-entrant end. If the wire is denuded exteriorly, the bared part forms a straight band running round the whole of the circumference. Friction pieces M and M′, are applied to the bared part of the helix, Fig. 17. When the ring is placed before the poles S and N of a magnet, the soft iron is magnetized by induction, and there occur in the ring two poles, N′ and S′, opposed to the poles S and N. If the ring revolves between the poles of a permanent magnet, the induced poles developed in the ring remain in the same relation with regard to the poles N and S, and are subject to displacement in the iron itself with a velocity equal, and of contrary direction to that of the ring. Whatever the rapidity of the movement, the poles N′ S′ remain fixed, and each part of the copper helix successively will pass before them.

An element of this helix is the seat of a current of a certain direction when traversing the path M S M′, and of a current of inverse direction to the first when passing through the path M′ N M. All the elements of the helix possess the same property, all the parts of the helix above the line M M′ will be traversed by currents of the same direction, and all parts beneath the line by a current of inverse direction to the preceding. These two currents are equal and opposed, and balance one another. As when two voltaic batteries composed of the same number of elements are coupled in opposition, it is necessary only to put the extremities of a circuit in communication with the poles common to the two batteries, and the currents become associated in quantity. Collectors of the current developed in the ring are established on the line M M′, where the contrary direction encounter each other.

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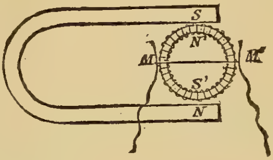

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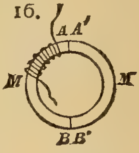

Insulated radial pieces R, Fig. 18, are each attached to the issuing end of a coil, and to the entrant end of the following coil. The currents are collected on the pieces R, as they would be on the denuded wire. Their bent parts, brought parallel to the axle, are carried through and beyond the interior of the ring, and are brought near one another upon a cylinder of small diameter. The friction brushes on the pieces R are in a plane perpendicular to the polar line, and at the middle or neutral points. The intensity of the current increases with the velocity of rotation; the electro-motive force is proportional to the velocity. Effects of tension or of quantity are produced by winding the ring with fine or coarse wire. With equal velocities of the ring the tension will be proportional to the number of convolutions of the wire; but the internal resistance increases in the same proportion. Thick wires give the best results.

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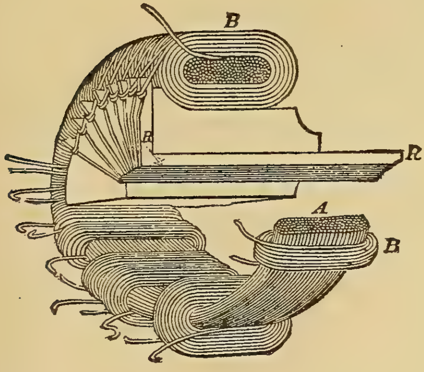
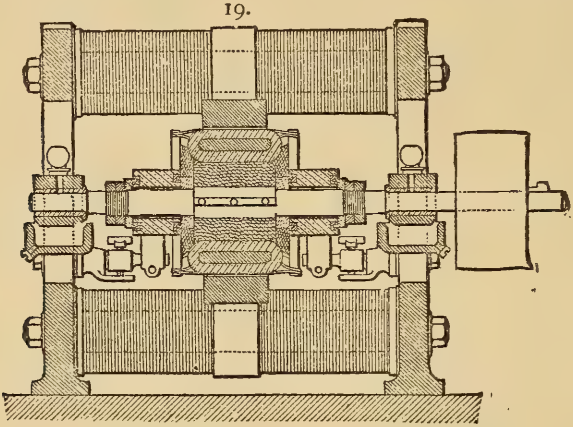


Various machines have been constructed on the Gramme principle for experimental purposes. The first type of this apparatus was horizontal, and gave a current equivalent to nearly three ordinary Bunsen elements. Since the invention by Jamin of laminated magnets, nearly all the laboratory machines have been constructed with magnets on this system.

Gramme's first light-machine gave a light of 7000 to 8000 candle-power. Its total weight amounted to 2200 lb. It had three movable rings and six bar electro-magnets. One of the rings excited the electro-magnet, the other two produced the working current. The copper wound on the electro-magnets weighed 550 lb.; that of the three rings, 165 lb. The space required, 31½ inches length, by 4 ft. 1¼ in. height. This machine lighted the clock-tower of the Houses of Parliament. It became slightly heated, and gave sparks between the metallic brushes and the bundle of conductors on which the current was collected.

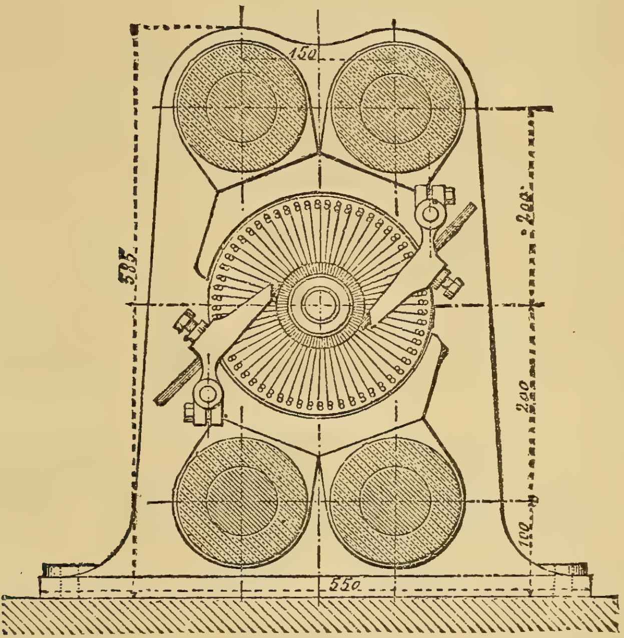
19.



Figs. 19 and 20, the latter to an enlarged scale, are of a machine which consists of two standards of cast iron arranged vertically, and connected by four iron bars serving as cores to electro-magnets. The axle is of steel, its bearings are relatively very long. The central ring, instead of a single wire attached by equal sections to a common collector, is formed of two wires of the same length, wound parallel on the soft iron, and connected to two collectors to receive the currents. The poles of the electro-magnet are of large size, and embrace seven-eighths of the total circumference of the central ring. Four brushes collect the currents produced. The electro-magnet is placed in the circuit. The total length of the machine, including the pulley, is 31½ in.; its width, 1 ft. 9½ in.; and its height, 23 in. Its weight is 880 lb.

The double coil is connected to 120 conductors, 60 on each side. Its exterior diameter is 8 in. The weight of wire wound on is 31 lb. The electro-magnet bars have a diameter of 2½ in., and a length of 15¾ in. The total weight of wire wound on the four bars is 211 lb. The winding of the wires on the ring is effected as if two complete bobbins were put one beside the other, and these two bobbins may be connected in tension or in quantity. Coupled in tension, they give a luminous intensity of 6400 candle-power at 700 revolutions a minute; coupled in quantity they give 16,000 candle-power with 1350 revolutions a minute.

20.



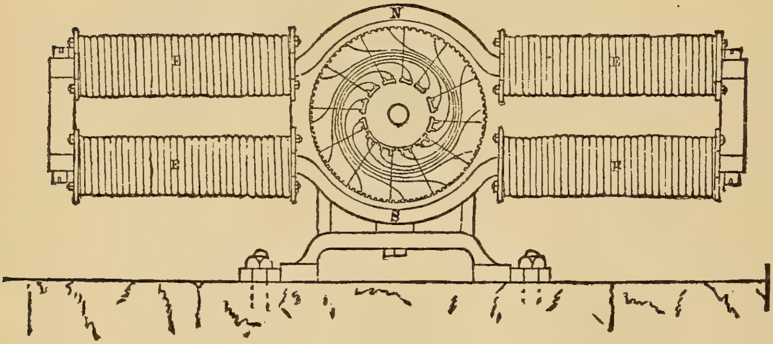
The following Table I. gives the results obtained with a Gramme machine of the workshop type, a Serrin lamp, and Gaudoin carbons. The motive power employed did not exceed 2 horse-power, when the machine was making 820 revolutions, and 3 horse-power at 900 revolutions. The lamp was distant 200 yards from the machine feeding it, and kept at a height of 15 ft.

TABLE I.—EARLY EXPERIMENTS WITH GRAMME MACHINES.

No. of Revolutions.	Distance of Observer from Lamp.	Candle-power Light.	Remarks.
	feet		
820	135	2464	The current was too feeble to maintain the carbon ⅛ in. apart.
820	67½	3600	
820	30	4120	
820	15	4800	Distance apart ⅛ in. regularly. Working satisfactorily.
820	7½	4896	
870	135	3200	
870	67½	4400	
870	30	6480	
870	15	8800	Too high tension. The carbons heat for considerable length. The light unsteady.
870	7½	9040	
920	135	3616	
920	67½	5632	
920	30	9656	
920	15	11362	
920	7½	11520	

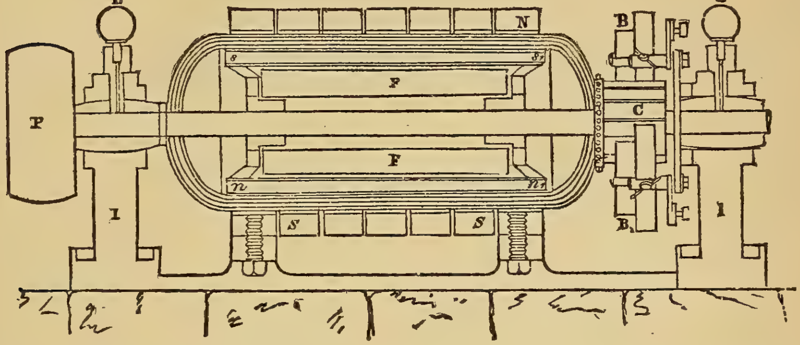
The electric current is produced in Siemens' dynamo-electric machine, Figs. 21 and 22, by the rotation of an insulated conductor of copper wire or armature coiled in several lengths, say 8, 12, 16 up to 28, and in several layers, longitudinally, upon a cylinder with a stationary iron core $n\,n_1\ s\,s_1$, so that the whole surface of the armature is covered with longitudinal wires and closed at both ends. This revolving armature is enclosed to the extent of two-thirds of its cylindrical surface by curved soft-iron bars.

21.



The curved bars are the prolongations of the cores of the electro-magnets E. The coils of the electro-magnet form, with the wires of the revolving armature, one continuous electric circuit, and when the armature is caused to rotate, an electric current, at first very feeble, is induced, by the remanent magnetism in the soft-iron bars, and directed through the collecting brushes into the electro-magnet coils, thus strengthening the magnetism of the iron bars, which again induce a still more powerful current in the revolving armature.

22.



At each revolution the maximum magnetic effect upon each convolution of the armature is produced just after it passes through the middle of both magnetic fields, which are in a vertical plane passing through the axis of the machine. The minimum effect is produced when in a plane at right angles or horizontal.

Induced currents are collected by brushes B, placed in contact with the commutator in the position which gives the strongest current.

The circumference of the revolving armature is divided into an even number of equal parts, each opposite pair being filled with two coils of wires, the ends of which are brought out and attached to a commutator.

The machine gives the following results for the various sizes:—

Revolutions per Minute.	Illuminating Power. Standard Candles.	Horse-power.	Weight. lb.
850	1,200	2	280
650	6,000	4	420
360	14,000	8	1,288

Only one Siemens or Serrin lamp can be burnt in the circuit of one of these machines.

The Gramme and similar machines are reversible; the rotation of the bobbin gives rise to an electric current; and reciprocally, if a current traverses the bobbin, the latter is caused to revolve. Because of this complete reversibility, all theories should be equally acceptable for both functions of the machine. The usual demonstrations do not fulfil this condition; but A. Breguet has shown that if the Gramme ring be considered as an extension of Barlow's wheel, theoretical views can be taken of the greatest simplicity. As is well known, Barlow's wheel consists of a metallic conductor, bent twice at right angles, and supported at the middle of its length on the point of a vertical axis, the axis of rotation of the system. The bent branches are parallel with this axis, and dip at their lower ends into a circular canal containing mercury; this canal is divided by ebonite partitions into equal parts, which are connected to the poles of a battery. The current from the battery passes to one semicircular canal of mercury, up one bent arm of the conductor, along the horizontal member, and down the other bent arm to the other semicircular canal of mercury. The whole apparatus is placed between the poles of a powerful permanent magnet, so that the diameter formed by the ebonite partitions is perpendicular to the line joining the magnet poles. On completion of the circuit, the conductor commences and continues to rotate. Breguet, to simplify explanation, terms the diameter formed by the partitions the diameter of commutation; and the magnetic field developed by the currents of the moving parts, the galvanic field, to avoid confusion with the magnetic field properly so called. If several convolutions are substituted for the single wire, the moment of revolving force will be increased proportionately to the number of the convolutions, provided that the resistance introduced by the increased length of wire does not sensibly reduce the strength of the current.

If a continuous frame be formed, so that in four crossings the wire on the upper part of the frame, as it is brought up, is at right angles to the crossing by which the wire was carried down, an approximation to the Alteneck or Siemens armature is obtained, the commutation in this case being arranged by four pieces pendent from the lower part of the frame.

If an iron cylindrical ring be arranged so that the axis of this ring is parallel to the axis of rotation of the wire conductor, which passes up the outside of one diameter of the cylinder, down upon the inside of the cylinder, across to the inside of the cylinder upon the farther part of the diameter, returning to the mercurial commutator by the outside of the cylindrical ring, an approximation is obtained to the Gramme ring. The iron cylinder acts as a magnetic screen, shutting off the action of the permanent magnet upon the interior wires, as in the Gramme machine.

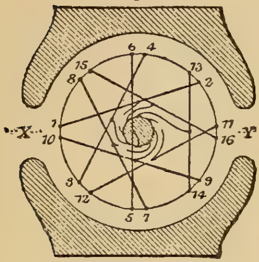
Breguet's views confirm the experiments made by Lippman, which go to prove that magnetic screens acting as armatures cease to fulfil this function when under movement of translation. This arises from the ring or screen, which in a state of rest concentrates or deviates upon itself the lines of force, when in movement taking up and abandoning an equal number of these lines in a given time, rendering its concentrative effect nil.

If d be the diameter, and e the width or length of a Gramme or Alteneck bobbin, the length of wire necessary to complete convolution is in the Gramme bobbin $4\,e$, and in the Alteneck bobbin $2\,(e + d)$, no account being taken of the extra length due to superposition of the layers of wire. If $4\,e < 2\,(e + d)$, the Gramme will be more effective, and if $4\,e > 2\,(e + d)$, less effective, than the Alteneck machine; if $4\,e = 2\,(e + d)$, the two machines will furnish identical currents. This equation being equivalent to $e = d$, according as the width or length of the bobbin is less or greater than its diameter, so will the Gramme machine be superior or inferior to that of Alteneck. Breguet considers that a drawback to the efficiency of the Alteneck machine is the necessity of fastening down the wires on the cylinder by bands, to prevent the wires, during centrifugal action, bowing out into contact with the exciting magnets, because these bands prevent the active wires being brought in such close proximity to the exciting magnets as in the Gramme machine, where the shortness of the wire does not call for this binding down.

Whilst the soft-iron armature of the Alteneck machine serves merely to reinforce the magnetic field in the region of the moving circuit, the annular core of the Gramme machine withdraws the internal wires of its armature from the normal action of the lines of force of the field. The angular displacement of the commutator occurring with such machines is not due to retardation consequent upon time necessary to magnetize or demagnetize the soft-iron cores, because such angular displacement occurs with machines not possessing iron cores; and if the machine is to be used as an electro-motor converting electricity into mechanical work, the angular displacement of the commutator brushes should be in a direction opposite to that of the rotation of the armature, and in the same direction as that of the rotation when the machine is employed as a generator of electric currents.

The following are various methods of winding the coils of the armatures of dynamo-electric machines described by Breguet.

23.



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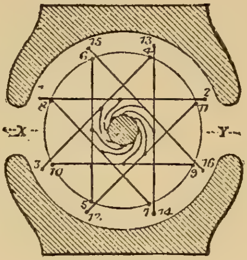
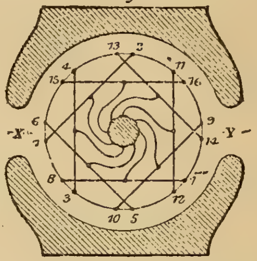


25.



The wire is wound longitudinally on a cylinder, of which Fig. 23 represents one of the ends. All the convolutions traverse the opposite end by one of the diameters. Starting from 1, the wire crosses the nearer end by 1, 2, and returns by 3 from the farther end of the cylinder, and so on. Fig. 23 shows how each transversal branch is connected to the eight metallic sectors, which during revolution of the cylinder are brought into contact with the wire brushes for collecting the current. The diameter X Y is that on which these points of contact occur. The poles of the magnet are above and beneath this diameter.

In Frölich's system the farther end is crossed by the wires following its diameters. The remaining connections will be understood from Fig. 24.

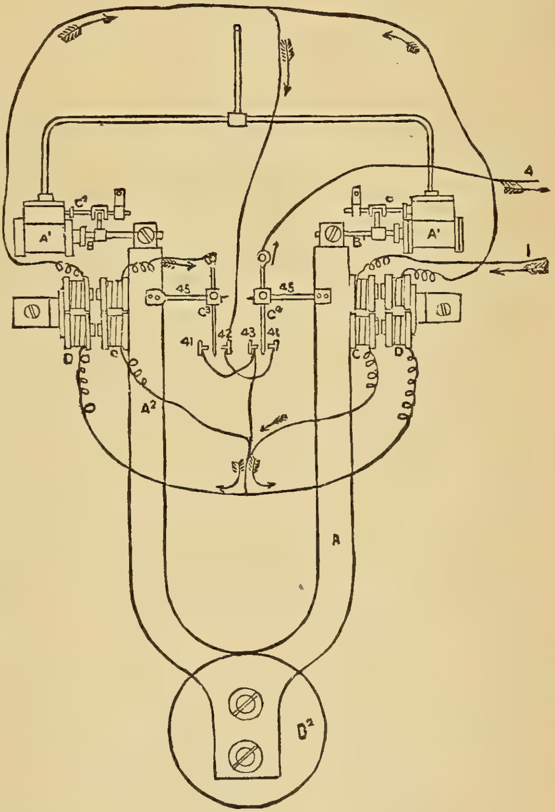
Breguet proposes two systems of winding, in which the wires crossing the farther end of the cylinder do not necessarily follow its diameter. One of these systems is shown in Fig. 25, for which superiority to the preceding is claimed on the ground that less length of wire is required to produce the same results, and by this means the heat developed in the bobbin by the passage of the currents is reduced, the economic coefficient being proportionally raised.

The following table gives the four systems of winding in the order of increasing merit, the last being the best, and the numerical column indicates the length of inactive wire as a function of the radius of the ends of the cylinder. The length of effective wire is supposed to be the same in each case :—

Frölich's system	30·8
Alteneck's "	30·5
Breguet's "	26 0

Edison's machine, Fig. 26, consists of a tuning-fork A^2, firmly attached to a stand B^2. This fork is of two prongs, but one only need be employed. The vibrating fork may be 2 yds. in length, and heavy in proportion. It has its regular rate of vibration, and the mechanism that keeps it in vibration is to move in harmony. A crank or revolving shaft may be employed, but it is preferable to use a small air, gas, or water engine, applied to each end of the fork. The cylinder A^1 contains a piston and a rod B^1, connected to the ends of the fork, and steam, gas, water, or other fluid under pressure acts within the cylinder, being admitted first to one side of the piston and then the other by a valve. The valve and directing rod C^3 are shown for this purpose. The fork A^2 may be a permanent magnet or an electro magnet, or it is provided with permanent or electro-magnets An electro-magnet, C, is shown on each prong of the fork, and opposed to these are the cores of the electro magnets D. Hence, as the fork is vibra-

26.

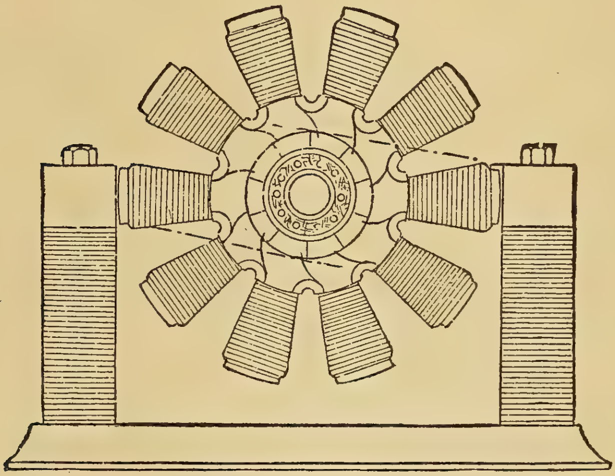


ted, a current is set up in the helix of each electro-magnet D, in one direction as the cores approach each other, and in the opposite direction as they recede. This alternate current is available for electric lights, but if it is desired to convert the current into one of continuity in the same direction, a commutator is employed, operated by the vibrations of the fork to change the circuit connections in each vibration, and thereby make the pulsations continuous on the line of one polarity. A portion of the current thus generated may pass through the helices of the electro-magnets C, to intensify them to the maximum power, and the remainder of the current is employed for any desired electrical operation. The commutator springs or levers C^3 and C^4 are operated by rods 45. When the prongs of the fork are moving from each other, the contact of the levers C^3 C^4 will be with the screws 40, 41, and the current will be from line 1 through C to C, thence to C^3 and to 41, 43, and to the electro-magnets D D; from these by 42 to 40 C^4 and line, as shown by the arrows. When the prongs A^2 are vibrating towards each other, the circuit will be through C^3 C C^3 42, in the reverse direction through the circuit and magnets D D to 43 and by C^4 to line.

De Meriten's machine consists of a series of electro-magnets in the form of a wheel, the north pole of one following the south pole of the adjacent magnet. Each electro-magnet, when the wheel is at rest, stands with its poles beneath the poles of a horseshoe permanent magnet. These permanent magnets are set in a fixed frame around the periphery of the wheel of electro-magnets. The insulated wires on the coils of the armature of the machine are all wound in the same direction, only the outer end of the wire of one coil is connected with the outer end of the wire of a coil next to it; whilst the inner end of the wire of the one coil communicates with the inner end of another coil next to it. The alternating currents produced are thus of the same sign throughout the whole ring. The two terminals of the wire on the ring, which constitute the two poles, communicate respectively with two copper rings fixed on the axis of the machine, and insulated from it. Two thick copper wires are in frictional contact with these rings, and are connected to terminal screws, from which the current is obtained. Multiple-circuit machines have been designed with the special purpose that the whole system of lighting should not be dependent upon the continuity of one circuit. This advantage necessitates a greater expenditure of motive power to produce the same light power.

Lontin introduced into England, in 1875, a plan for converting the whole of the electricity produced in the revolving armature of a machine, into the exciting magnets, instead of a portion. This had the effect of rendering the exciting magnets very powerful in a short time, and the magnetic resistance to the rotation of the coil increased in a few minutes to the extent that it was found difficult to overcome it. The circuit was then broken by an automatic commutator, and the special working circuit inserted. In 1876, Lontin constructed a machine to overcome the difficulty of the heat generated in the coils of the former machine. This latter consisted of an armature in the form of a wheel, with a central boss and spokes of soft iron, mounted on a shaft to which rotary motion could be imparted, Fig. 27. Each soft-iron spoke of the wheel has a coil of wire wound on it, and is, in fact, an electro-magnet, which becomes a source of induced electricity when the wheel is revolved between the poles of a fixed electro-magnet. The residual magnetism of the cores of the electro-magnets is sufficient at first to generate a feeble current in the coils when the wheel is revolved; and a portion of this current, kept in one direction by a commutator, is diverted in the usual manner into the fixed electro-magnets, to intensify them.

27.



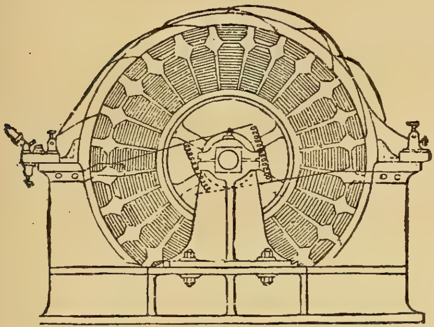
One or several of these induction wheels may be applied on the same shaft, placing them opposite one or more series of permanent or electro-magnets. When two wheels are fixed on the same shaft, one of them can supply currents exclusively for feeding the electro-magnets, and the currents from the other can be used for external work. If the currents are required to be of only one direction, a commutator or collector is employed, and one for each coil or pair of coils is placed on the shaft, to each being attached the two ends of the wire of the corresponding coil or pair of coils. When merely collectors are used, all the coils on the wheel are connected up in series, so as to form a completely closed circuit as in Fig. 27. All the coils approaching a pole of the electro-magnet are inversely electrified to those receding from the same pole. A metal strip is arranged opposite the pole of the electro-magnet, to collect, by contact, the electricity generated in the coil at the instant that its polarity becomes reversed; a similar rubber is also applied opposite the other pole of the electro-magnet. In order to avoid oxidizing effect under the action of sparks, the commutators are enclosed in a bath of non-drying oil.

Lontin's greatest improvement is the construction of dynamo-electric machines with inducing electro-magnets having a rotary motion, whilst the induced coils are stationary. Figs. 28 and 29 are of this machine. The coils of the induction wheel are in this case the inducers, and are transformed into electro-magnets by the current of a spare magneto-electric machine passed through them. On rotation of the wheel they induce in the surrounding coils a series of currents, which can be utilized, without the use of collector or contact-ring. A machine having 50 induced coils, would have 50 sources of electricity that could be employed either separately or combined.

The fixed electro-magnet shown in Fig. 27 may have its cores prolonged, so that more than one coil of insulated wire can be placed upon them. Thus, when the wheel is turned into an inducer, by reason of the currents already induced in it by the electro-magnets, it will in its turn induce currents in the additional coils, and these currents can be utilized for electric lighting. Figs. 28 and 29 are of a machine employed as a generator to supply currents to the dividing machine, Fig. 30.

The dividing machine consists of a revolving drum carrying a series of radial magnets. The coils of these radial magnets are connected together, so that one magnet has its positive pole at the outside end, and the succeeding magnet its positive pole at the inside end. The radial magnets are thus made to alternate their poles considered as a circumference to the wheel. By this arrangement the revolving wheel induces a number of alternate currents, equal to half the number of spokes. An exterior commutator, which may be connected up in many different ways, enables these currents to be combined as required. This duplex Lontin system gives a total illuminating power of 12,000 candles. The generating machine is driven at 250 revolutions, and the distributing or dividing machine at 400 a minute. With an engine of 8 horse-power nominal, 12 light circuits can be maintained.

28.



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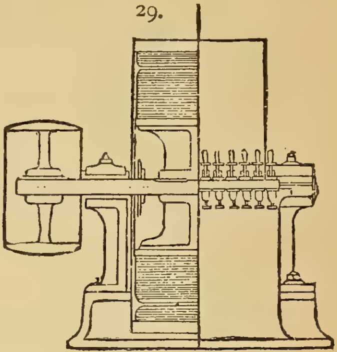
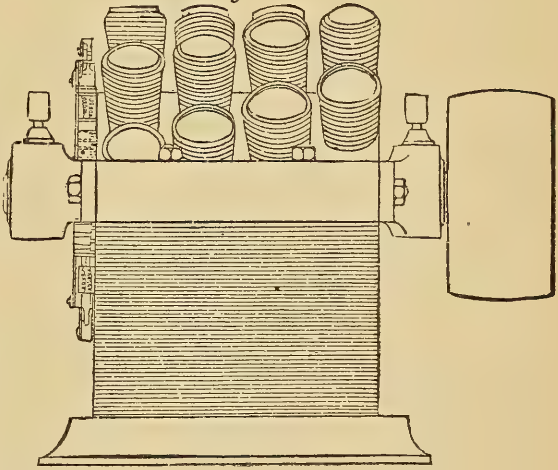


The Gramme distributor Figs. 31 and 32, consists of a ring of iron wound with coils of insulated copper wire, alternately right and left handed, the wire being coiled in one direction, so as to cover one-eighth part of the ring, then in the opposite direction for the next eighth part, each of the eight sections of the ring being wound in the reverse direction to the winding of the two adjacent sections. This ring may be considered as eight curved electro-magnets placed

30.



end to end, with their similar poles in contact, so as to form a circle. It is rigidly fixed in a vertical position to the solid framing of the apparatus, the inducing electro-magnets revolving within it.

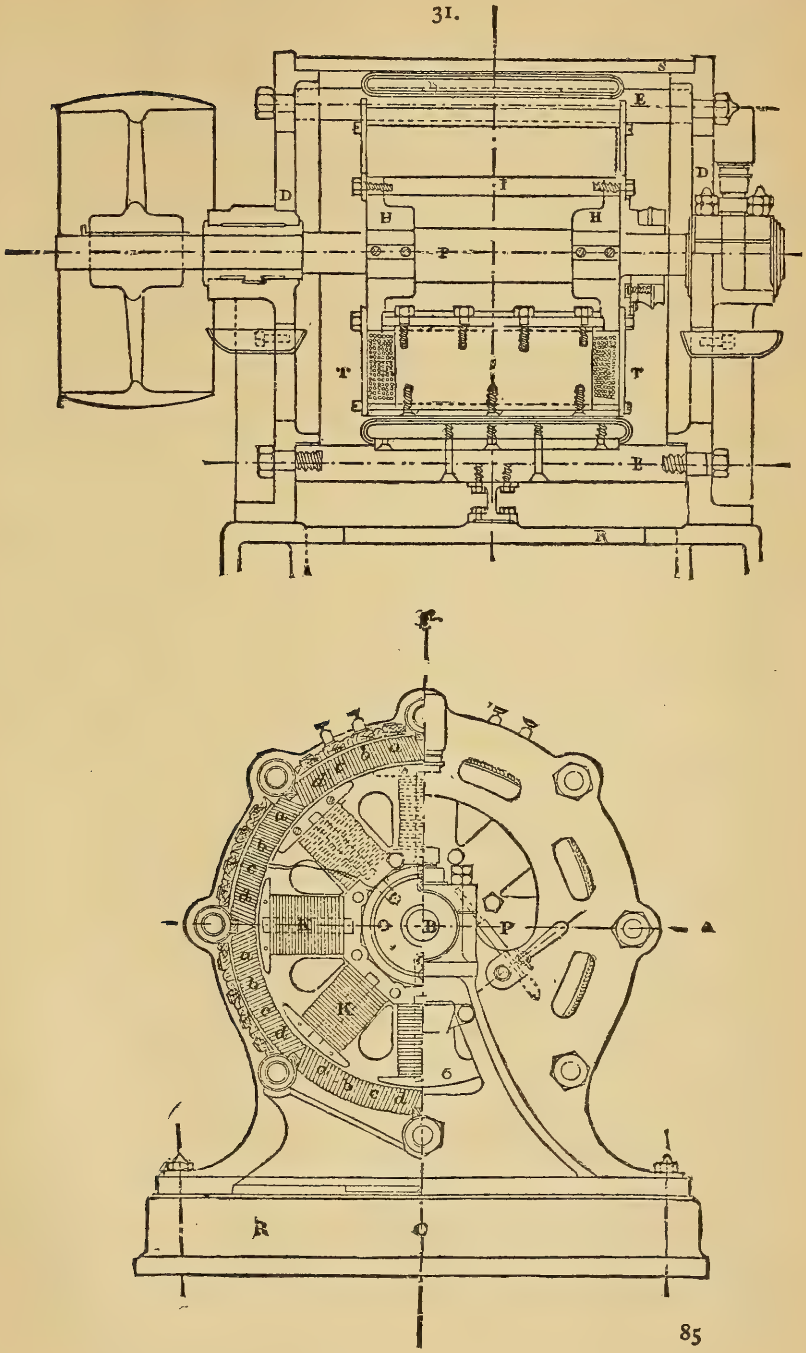
There are eight electro-magnets fixed radially to a central boss revolving upon a horizontal shaft, upon which is a pulley, driven by a band from a motor. These radial flat electro-magnets are wound alternately right and left handed, and their alternate ends are consequently of opposite polarity. The cores of these magnets are extended by plates to increase the area of the magnetic fluid by which currents are induced in the coils of the ring.

There is no self-contained apparatus for producing the current by which the electro-magnets are magnetized, but a small Gramme machine of the continuous current type is employed, and is driven by a separate strap. The current from this machine is caused to circulate in the coils of the rotating radial electro-magnets, by which these are magnetized to saturation. Each section of the ring is built up of four subsections, *a b c d*, Fig. 32, and all these subsections of any one section are wound in the same direction. This subdivision admits of the connecting-up of the subsections into 32, 16, 8 or 4 circuits. All the subsections marked *a* are influenced by the rotating magnets in precisely similar manner, because the influence of a north pole upon a coil wound in a right-handed direction is the same as that of a south pole upon a coil wound in a left-handed direction. Similarly, the currents in all the *b* coils are of one direction, whatever the position of the rotating magnets. Thus, all the coils similarly marked can be connected into one circuit, and terminal screws are provided for the required arrangement. The current from the small machine is led to the rotating magnets through the flat brushes of silvered copper wire attached to the framework of the machine, and in rubbing contact with two insulated copper cylinders, one connected to each end of the magnet circuit.

A largest sized machine supplies 16 Jablochkoff candles, each of 1000 candle-power, at a speed of 600 revolutions a minute, absorbing 16 horse-power.

On the mechanical efficiency of dynamo-electric machines, Paget Higgs states, there can be nothing done in the inter-comparison of any natural force until accurate measurements have been made. For these measurements the electrical engineer has mainly to look to the labours of the committee on dynamo-electric machines formed by the Franklin Institute, and to Houston and Thomson's report as to

31.



the ratio of efficiency in the conversion of motive power into electricity.

In entering this comparatively new field of research, peculiar difficulties occurred, owing to conditions that do not exist in the various forms of batteries used as sources of electrical power. In many battery circuits a high external resistance may be employed, and the electro-motive force remains comparatively constant, while in dynamo-electric machines, in which the reaction principle is employed, the introduction of a very high external resistance into the circuit must be necessarily attended by decided variations in the electro-motive force, due to changes in the intensity of the magnetic field in which the currents have their origin. Moreover, a considerable difficulty is experienced in the great variations in the behaviour of those machines when the resistance of the arc, or that of the external work, is changed. Changes, due to loss of conductivity by heating, also take place in the machine itself.

These variations are also attended by changes in the power required to drive the engine, and in the speed of running, which again react on the current generated.

There are certain normal conditions in the running of dynamo-electric machines designed for lighting, under which all measurements must be made, viz.:—

The circuit must be closed, since on opening, all electrical manifestations cease.

The circuit must be closed through an external resistance equal to that of the arc of the machine.

The arc taken as the standard must be the normal arc of the machine. This condition can only be fulfilled by noticing the behaviour of the machine, while running, as to the absence of sparks at the commutator, the heating of the machine, the regularity of action in the consumption of carbons in the lamp, &c.

The speed of the machine must be, as nearly as possible, constant.

The power required to maintain a given rate of speed must be, as nearly as possible, constant.

The machines submitted to the committee of the Franklin Institute for determination were as follows:

Two machines of different size, and of somewhat different detailed construction, built according to the invention of C. F. Brush, and styled respectively in the report as A^1, the larger of the two machines, and A^2, the smaller.

Two machines known as the Wallace-Farmer machines, differing in size, and in minor details of construction, and designated respectively as B^1, the larger of the two, and B^2, the smaller. In the case of the machine B^1, the experiments were discontinued after the measurement of the resistance was made, insufficient power being at disposal to maintain the machine at its proper rate of speed.

A Gramme machine of the ordinary construction.

All the above machines are constructed so that the whole current traverses the coils of the field magnets, being single current machines, in which the reaction principle is employed. In the case of the machine designated A^3, the commutators are so arranged as to permit the use of two separate circuits when desired.

For the purpose of preserving a ready measure of the current produced by each machine, under normal conditions, a shunt was constructed, by which an inconsiderable but definite proportion of the current was caused to traverse the coils of a galvanometer, thus giving with each machine a convenient deflection, which could at any time be reproduced. As the interposition of this shunt in the circuit did not appreciably increase its resistance, the normal conditions of running were preserved.

As indicating the preservation of normal conditions in any case, the speed of running and the resistances being the same as in any previous run, it was found that when there was an equal expenditure of power, as indicated by the dynamometer, the current produced, as indicated by the galvanometer, was in each case the same.

Certain of the machines experimented with, heated considerably on a long run; most of the tests, therefore, were made when the machines were as nearly as possible at about the temperature of the surrounding air. It is evident that no other standard could be well adopted, as under a prolonged run the temperature of the different parts of the machine would increase very unequally; and, moreover, it would be impossible to make any reliable measurements of the temperatures of many such parts.

In measuring the resistance of the machines, a Wheatstone's bridge, with a sliding contact, was used, in connection with a delicate galvanometer and a suitable voltaic battery. In taking the resistances of the machines, several measurements were made with the armatures in different positions, and the mean of these measurements taken as the true resistance.

It was, of course, a matter of the greatest importance to obtain a value for the resistance of the arc in any case, since upon the relative values of this resistance, and that of the machine, the efficiency would in any given case to a great extent depend. In each case, the arc of which the resistance was to be taken, was that which was obtained when each machine was giving its average results as to steadiness of light and constancy of the galvanometer deflection.

The method adopted for the measurement of the arc was that of substitution, in which a resistance of German silver wire, immersed in water, was substituted for the arc, without altering any of the conditions of running. This substituted resistance was afterwards measured in the usual way, and gave, of course, the resistance of the arc. It could, therefore, when so desired, serve as a substitute for the arc. No other method of obtaining the arc resistance appeared applicable, since the constancy of the resistance of the arc required the passage of the entire current through the carbons.

It may be mentioned, as an interesting fact in this connection, that when the current flowing was great, the arc corresponding thereto had a much lower resistance than when the current was small. This fact is, of course, due to increased vaporization, consequent on increased temperature in the arc.

In determining the true arc resistance, the resistance of the electric lamp controlling the arc was measured separately, and deducted from the result obtained with the German silver wire substitute.

For ease of obtaining a resistance of German silver wire equal in any case to that of the arc, a simple rheostat was constructed, by winding, upon an open frame, such a length of wire as was judged to be in excess of the resistances of any of the arcs to be measured. By means of a sliding contact, successive lengths of the wire were added until the conditions were reproduced. With this arrangement, no difficulty was experienced in reproducing the same conditions of normal running as when the arc was used. The same conducting wires were used throughout these experiments. Being of heavy copper, their resistance was low, about ·016 ohm.

To determine the value of the current two methods were selected, one based on the production of heat in a circuit of known resistance, and the other upon the comparison of a definite proportion of the current with that of a Daniell's battery.

In the application of the first method, eight litres of water, at a known temperature, were taken, and placed in a suitable non-conducting vessel. In this was immersed the German silver wire, and the sliding contact adjusted to afford a resistance equal to that of the normal arc of the machine under consideration. This was now introduced into the circuit of the machine. All these arrangements having been made, the temperature of the water was accurately obtained by a delicate thermometer. The current from the machine running under normal conditions was allowed to pass, for a definite time, through the calorimeter so provided. From the data thus obtained, after making the necessary corrections as to the weight of the water employed, the total heating effect in the arc and the lamp, as given in Table II., was deduced.

Since the heat in various portions of an electrical circuit is directly proportional to the resistance of those portions, the total heat of the circuit was easily calculated, and is given in Table III., in English heat-units. For ease of reference, the constant has been given for conversion of these units into the metrical units of heat.

Having thus obtained the heating effect, the electrical current is—

$$C=\sqrt{\frac{Wh \times 772}{Rtc}},$$

where C = the Weber current an ohm, W the weight of water in pounds, h the increase of temperature in degrees F., 772 Joule's constant, R the resistance in ohms, t the time in seconds, and c the constant, ·737335, the equivalent in foot-pounds of one weber an ohm a second. The currents so deduced for the different machines are given in Table VI.

The other method employed for obtaining the current, the comparison of a definite portion thereof with the current from a Daniell's battery, was as follows:—A shunt was constructed, of which one division of the circuit was ·12 ohm, and the other 3000 ohms. In this latter division of the circuit was placed a low-resistance galvanometer, on which convenient deflections were obtained. This shunt being placed in the circuit of the machine, the galvanometer deflections were carefully noted. To the resistance afforded by the shunt, such additional resistance was added, as to make the whole equal to that of the normal arc of the machine. These substituted resistances were immersed in water, in order to maintain an equable temperature.

Three Daniell's cells were carefully set up and put in circuit with the same galvanometer, and with a set of standard resistance coils. Resistances were unplugged sufficient to produce the same deflections as those noted with the shunt above mentioned. The shunt ratio, as nearly as could conveniently be obtained, was $\frac{1}{25000}$. Then the formula

$$C = \frac{s\,n \times 1\cdot079}{R},$$

where C equals the Weber current, s the reciprocal of the shunt ratio, n the number of cells employed, 1·079 the assumed normal value of the electro-motive force of a Daniell's cell, and R the resistances in the circuit with the battery, gives at once the current. In comparison with the total resistances of the circuit, the internal resistance of the battery was so small as to be neglected.

The results obtained, Table II., were as follows:—

TABLE II.—COMPARISON OF RESISTANCES.

Name of Machine.	Shunt Ratio.	No of Daniell's Cells.	Resistances Unplugged.	Speed of Machine.
			ohms.	rev.
Large Brush	$\frac{1}{25000}$	3	2710	1340
Small "	"	"	3700	1400
Wallace-Farmer	"	"	8320	844
	"	"	6980	1044
Gramme	"	"	4800	800

The Weber currents, as calculated from the above data, are given in Table VI.

From the results thus derived the electro-motive force was deduced from the general formula—

$$E = C \times R.$$

The electro-motive force thus calculated will be found in Table VI.

Statements are frequently made, when speaking of certain dynamo-electric machines, that they are equal to a given number of Daniell's or other well-known battery cells. It is evident, however, that no such comparison can properly be made, since the electro-motive force of a dynamo-electric machine, in which the reaction principle is employed, changes considerably with any change in the relative resistances of the circuit of which it forms a part, while that of any good form of battery, disregarding polarization, remains approximately constant. The internal resistance of dynamo-electric machines is, as a rule, very much lower than that of any ordinary series of battery cells, as generally constructed, and, therefore, to obtain with a battery conditions equivalent to those in a dynamo-electric machine, a sufficient number of cells in series would have to be employed to give the same electro-motive force; while, at the same time, the size of the cells, or their number in multiple arc, would require to be such that the internal resistance should equal that of the machine.

Suppose, for example, that it be desired to replace the large Brush machine by a battery whose electro-motive force and internal and external resistances are all equal to that of the machine, and that as a standard a Daniell's cell of an internal resistance, say, of one ohm is adopted. Referring to Table VI., the electro-motive force of this machine is about 39 volts, to produce which about 37 cells, in series, would be required; but by Table IV., the internal resistance of this machine is about ·49 ohm. To reduce the resistance of our standard cell to this figure, when 37 cells are employed in series, 76 cells, in multiple arc, would be required. Therefore, the total number of cells necessary to replace this machine would equal 37 × 76, or 2812 cells, working over the same external resistance. It must be borne in mind, however, that although the machine is equal to 2812 of the cells taken, no other arrangement of these cells than that mentioned, namely, 76 in multiple arc and 37 in series, could reproduce the same conditions, and, moreover, the external resistances must be the same. The same principles, applied to other machines, would, when the internal resistance was great, require a large number of cells, but arranged in such a way as to be extremely wasteful, from by far the greater portion of the work being done in overcoming the resistance of the battery itself. The true comparative measure of the efficiency of dynamo-electric machines, as means for converting motive power into work derived from electrical currents, whether as light, heat, or chemical decomposition, is found by comparing the units of work consumed with the equivalent units of work appearing in the circuit external to the machine. In Table V. the comparative data are given. In the first column the dynamometer reading gives the total power consumed, from which are to be deduced the figures given in the second column, being the work expended in friction, and in overcoming the resistance of the air; although, of course, it must be borne in mind that that machine is the most economical in which, other things being equal, the resistance of the air and the friction are the least. The third column gives the total power expended in producing electrical effects, a portion only of which, however, appears in the effective circuit, the remainder being variously consumed in the production of local circuits in the different masses of metal composing the machines. This work eventually appears as heat in the machine. Columns four, five and six give respectively the relative amounts of power variously appearing as heat in the arc, in the entire circuit, and as heat due to local circuits in the conducting masses of metal in the machine, irrespective of the wire. This latter consumption of force may be conveniently described as due to the local action of the machine, and is manifestly comparable to the well-known local action of the voltaic battery, since in each case it not only acts to diminish the effective current produced, but also adds to the cost.

No determination made with an unknown or abnormal external resistance can be of any value, since the proportion of work done, in the several portions of an electrical circuit, depends upon, and varies with, the resistances they offer to its passage. If, therefore, in separate determinations with any particular machine, the resistance of that part of a circuit of which the work is measured be in one instance large in proportion to the remainder of the circuit, and in another small, the two measurements thus made would give widely different results, since in the case where a large resistance was interposed in this part of the circuit, the percentage of the total work appearing there would be greater than if the small resistance had been used.

When an attempt has been made to determine the efficiency of a single machine, or of the relative efficiency of a number of machines, by noting the quantity of gas evolved in a voltameter, or by the electrolysis of copper sulphate in a decomposing cell, when the resistance of the voltameter or decomposing cell did not represent the normal working resistance, it is manifest that the results cannot properly be taken as a measure of the actual efficiency.

In Table IV. it will be found that, in general, where the machine used had a high internal resistance, the arc resistance normal to it was very high, but they are not necessarily dependent upon each other. The arc resistance depends on the intensity of the current, the nature of the carbons, and on the distance apart. Other conditions being the same, the resistance of the arc is less when the current is great.

Since all the machines examined were built for lighting, it will readily be seen that, other things being equal, that machine is the most economical in which the work done in the arc bears a considerable proportion to that done in the whole circuit, and since, with any given current, the work is proportional to the resistance, we have in Table IV. the data for comparison in this regard. For example, in the second determination of A^1, the large Brush machine, the resistance of the arc constitutes considerably more than one-half the total resistance of the entire circuit, while in B^2, the small Wallace-Farmer machine, it constitutes somewhat more than one-third the total resistance. These relative resistances give, of course, only the proportion of the current generated, which is utilized in the arc as light and heat, the conditions of power consumed to produce the current not being there expressed.

During any continued run, the heating of the wire of the machine, either directly by the current, or indirectly from conduction from those parts of the machine heated by local action, as explained in a former part of this report, produced an increased resistance, and a consequent falling off in the effective current. Thus in Table IV. at the temperature of 73·5° F., A^1, the large Brush machine, had a resistance of ·485 ohm, while at 88° F., at the armature coils, it was ·495 ohm. These differences were still more marked in the case of B^1.

In A^2, the small Brush machine, it will be noticed that two separate values are given for the resistance of the machine. These correspond to different connections, the resistance, 1·239 ohm, being the connection at the commutator for low resistance, the double connecting wires being coupled in multiple arc, while 5·044 ohms represent the resistance when the sections of the double conductor are coupled at the commutator in series.

TABLE III.—SHOWING WEIGHT, POWER ABSORBED, LIGHT PRODUCED, &C., BY DYNAMO-ELECTRIC MACHINES, tested by a Committee of the Franklin Institute, 1877–78.

Name of Machine.	Weight in Pounds.	Copper Wire in				Revolutions of Armature a Minute.	Foot-pounds of Power Consumed.	Horse-power.	Light produced in Standard Candles.		Foot-pounds of Power Consumed each Candle-light.	Size of Carbons.	Length of Carbon Consum'd an hour.	
		Armature.		Field Magnets.										
		Size.	Weight.	Size.	Weight.				Total.	Each H.-P.			+	−
		in.	lb.	in.	lb.									
Large Brush ..	475	·081	32	·134	100	1340	107·603	3·26	1230	377	87·4	$\frac{3}{8}\times\frac{3}{8}$	1·78	·34
Small " ..	390	·063	24	·096	80	1400	124·248	3·76	900	339	137·	$\frac{3}{8}\times\frac{3}{8}$	1·91	·58
Large Wallace ..	600	·042	50	·114	125	800	..	..	823	..	..	..	..	..
Small " ..	350	·043	18$\frac{3}{4}$	·098	41	1000	128·544	3·89	440	113	292·	$\frac{1}{4}\times\frac{1}{4}$	2·45	·073
Gramme	366	·059	104	·108	104	800	60·992	1·84	705	383	85·	$\frac{1}{4}\times\frac{1}{4}$	3·15	·55

TABLE IV.—RESISTANCES OF DYNAMO-ELECTRIC MACHINES.

Name of Machine.	Temperature in Degrees F.	Resistances.		Resistance of Conducting Wire.	Resistance of Lamp exclusive of Arc.	Corrected Resistances.		Total Resistance of the Circuit, Ohms.	Remarks.
		Of Machine + Conductor.	Of Arc + Lamp.			Of Machine — Conductor.	Of Arc — Lamp.		
A¹. Large Brush ..	73½	·485	·57	·016	·032	·483	·54	1·055	At beginning of run.
A¹. “ “ ..	88	·495	·82	·016	·032	·493	·79	1·315	After running 25 minutes.
A². Small ‘ ..	74	1·255	1·70	·016	·032	1·239	1·67	2·955	Arranged for low resistance.
A². “ “ ..	74	5·06	..	·016	..	5·044	..	..	“ high “
B¹. Large Wallace	74	4·60	1·98	·016	·032	4·584	1·95	6·58	Machine cold.
B². “ “ ..	118	5·13	..	·016	..	..	..	..	After 40 minutes' run.
B². Small “ ..	74	4·96	2·87	·016	·1025	4·944	2·77	7 83	At 844 revolutions.
B². “ “ ..	74	4·96	3·24	·016	·1025	4·944	3·18	8·24	At 1000 “
Gramme	68	1·685	1·35	·016	·1025	1·667	1·25	3·04	Arc not normal.
“	68	1·685	1·97	·016	·1025	1·667	1·87	3·66	Arc normal.

TABLE V.—THERMIC EFFECTS OF DYNAMO-ELECTRIC MACHINES.

Name of Machine.	Galvanometer Deflection with Shunt.	Heating Effect in Arc and Lamp.			Resistance of Calorimeter, equal to Arc.	Heat in Arc and Lamp, in Lb., H_2O, 1° Fahr.	Total heat of the Circuit, in Lb., H_2O, 1° Fahr.	Heat each Ohm, a Second.	Speed of Machine, Revolutions a Min.	Dynamometer Reading, including Friction.
		Pounds, H_2O.	Increase, Degrees Fahr.	Duration of Run.						
A¹. Large Brush	° 51½	18·64	23·25	10	·82	43·338	69·49	·881	1340	107606
A². Small “	34	18·63	9·09	5	1·70	33·87	58·87	·332	1200	117700
A². “ “	37	18·63	18·66	8	1·70	43·45	75·57	·426	1400	124248
B². “ Wallace	25½	18·63	11·50	12	2·87	17·85	48·70	·104	844	97068
B². “ “	55½	18·63	4·92	6	2·87	15·28	41·69	·089	844	97068
B². “ “	24½	18·64	10·75	10	3·28	20 04	50 34	·102	1040	128544
Gramme	38	18·64	16·25	10	1·97	30·29	56·28	·256	800	60992

For conversion to metrical heat units, 1 lb. water, 1° F. = 259·185 grammes of water, 1° C.

Referring to Table V., the numbers given in the column headed, Heat in arc and lamp, are the measure of the total heating power in that portion of the circuit external to the machine. They do not, however, in the case of any machine, represent the energy which is available for the production of light, which depends also on the nature and the amount of the resistance over which it is expended.

For example, the heat in arc and lamp are practically the same in each of the Brush machines, if the measurement of the smaller of these machines be taken at the higher speed. The amount of light produced, however, is not the same in these two instances, being considerably greater in the case of the larger machine.

The explanation of this apparent anomaly is undoubtedly to be found in the different resistances of the arcs in the two cases. In the large Brush machine the carbons are nearer together than when the small machine is used. This suggests the very plausible explanation, that the cause of the difference is to be attributed to the fact that although the total heating effect is equal in each case, when the large machine is used, the heat produced is evolved in a smaller space, and its temperature, and consequent light-giving power, thereby largely increased.

It would seem, indeed, that any future improvements made in the direction of obtaining an increased intensity of light from a given current, will be by concentrating the resistance normal to the arc in the most limited space practicable, thereby increasing the intensity of the heat, and, consequently, its attendant light.

It may be noted in this connection, that in all the cases in which the resistance of the arc was low, the photometric intensity was high. This, indeed, might naturally be expected, since a great intensity of heat would, under existing conditions of the use of the arc, admit of increased vaporization, and consequent lowering of the resistance.

In the column headed, Total heat of circuit, are given the quantities of heat developed in the whole circuit, which numbers, compared with those in the preceding column, furnish us with the relative proportions of the work of the circuit which appear in the arc and lamp.

The column headed, Heat each ohm a second, gives the relative work an ohm of resistance in each case, and these numbers, multiplied by the total resistance, give the total energy of the current expressed in heat units a second.

In Table VI. are given the results of calculation and measurement, as to the electrical work of each machine.

It is evident, to those acquainted with the principles of electrical science, that the Weber current and the electro-motive force, are the data for comparing the work of these machines with that of any other machine or battery, whether used for light, heat, electrolysis, or any other form of electrical work.

As might be supposed, the values given in Table VI., of the Weber current, approximate relatively to the photometric values, as will be seen from an examination of that part of the general report of the committee relating to photometric measurements.

The values of the Weber current, as deduced from the heat developed, and from the comparison with a Daniell's cell, do not exactly agree; nor could this have been expected, when the difficulty of minutely reproducing the conditions as to speed and resistance is considered.

By comparison of the electro-motive force of the different machines, it appears that no definite unit seems to have been aimed at by all the makers as that best adapted to the production of light.

TABLE VI.—CURRENT AND ELECTRO-MOTIVE FORCE OF DYNAMO-ELECTRIC MACHINES.

Name of Machine.	Weber Current each Ohm a Second.		Electro-motive Force in Volts.		Per cent. of the Work of Current appearing in the Arc.	Corresponding Dynamometric Values.	Remarks.	
	From heat developed.	By Comparison with Daniell's Battery.	Calculated from Heat and Resistances.	By Comparison with Daniell's Battery.				Rev.
A^1. Large Brush	30·37	29·87	39·94	39·28	60·08	107606	Speed,	1340
A^2. Small " ..	18·63	..	55·05	..	..	117700	"	1200
A^2. " " ..	21·12	21·87	62·41	64·43	56·51	124248	"	1400
B^2. Small Wallace	10·42	9·73	81 59	76·19	35·38	96068	"	844
B^2. " " ..	9·64	..	75·48	..	..	..	"	844
B^2. " " ..	10·33	11·16	85·12	91·96	38·59	128544	"	1040
Gramme	16·38	16·83	59·95	61·71	51·09	60992	"	800

TABLE VII.—EFFECTS OF DYNAMO-ELECTRIC MACHINES IN FOOT-POUNDS A MINUTE.

Name of Machine.	Dynamometer Reading, Foot-lb. Consumed.	Friction and Resistance of Air.	Foot-lb. Consumed after Deducting Friction.	Foot-lb. appearing in Arc as Heat.	Foot-lb. appearing in whole Circuit.	Foot-lb. unaccounted for in the Circuit.	Per cent. of Power utilized in Arc.	Per cent. of Effect after Deducting Friction.
A^1. Large Brush	107,606	17,950	89,656	33,457	53,646	36,010	31	37½
A^2. Small " ..	117,700	12,328	105,372	26,148	45,448	59,924	22	25
A^2. " " ..	124,248	14,976	109,272	33,543	58,340	50,932	27	31
B^2. Small Wallace	97,068	7,800	89,268	13,780	37,596	51,672	14	15½
B^2. " " ..	128,544	11,072	117,472	15,469	38,862	78,610	12	13
Gramme	60,992	4,512	56,480	23,384	43,448	13,032	38	41

For conversion into Gramme metres, 1 foot-pound = 138 Gramme-metres, nearly.

Table VII. is designed especially to permit a legitimate comparison of the relative efficiency of the machines, as well as their actual efficiency in converting motive power into current. The actual dynamometer reading is given in the first column. On account of differences of construction and differences in speed of running, the friction and resistance of the air vary greatly, being least with the Gramme, as might be expected, since the form of the revolving armature, and the speed of the machine conduce to this result. This is, of course, a point greatly in favour of the Gramme machine.

That part of the power expended available for producing current is given in the third column, being the remainder, after deducting the friction, as above mentioned; but this power is not in any case fully utilized in the normal circuit. This is found to be the case by comparing calculations of the total work of the circuit in foot-pounds, as given in the appropriate column, with the amount expended in producing such circuit.

For instance, in the case of A^1, the large Brush machine, the available force for producing current is 89,656 foot-pounds in a minute, of which only 53,646 reappear as heat in the circuit. The balance is most probably expended in the production of local currents in the various conducting masses of metal composing the machine. The amount thus expended in local action is given in the column designated, Foot-lb. unaccounted for in the circuit. A comparison of the figures in this column is decidedly in favour of the Gramme machine, it requiring the smallest proportion of power expended to be lost in local action. When, however, we consider that the current produced by the large Brush machine is nearly double that produced by the Gramme, the disproportion in the local action is not so great.

The columns containing the percentages of power utilized in the arc, and useful effect after deducting friction, need no special comment.

The determinations made enabled the following opinions to be formed as to the comparative merits of the machines submitted for examination :—

The Gramme machine is the most economical, considered as a means for converting motive power into electrical current, giving in the arc a useful result equal to 38 per cent., or to 41 per cent. after deducting friction and the resistance of the air. In this machine the loss of power in friction and local action is the least, the speed being comparatively low. If the resistance of the arc is kept normal, very little heating of the machine results, and there is almost entire absence of sparks at the commutator.

The large Brush machine comes next in order of efficiency, giving in the arc a useful effect equal to 31 per cent. of the total power used, or 37½ per cent. after deducting friction. This machine is, indeed, but little inferior in this respect to the Gramme, having, however, the disadvantages of high speed, and a greater proportionate loss of power in friction, &c. This loss is nearly compensated by the advantage this machine possesses over the others of working with a high external, compared with the internal, resistance, this also ensuring comparative absence of heating in the machine. This machine gave the most powerful current, and consequently the greatest light.

The small Brush machine stands third in efficiency, giving in the arc a useful result equal to 27 per cent., or 31 per cent. after deducting friction. Although somewhat inferior to the Gramme, it is, nevertheless, a machine admirably adapted to the production of intense currents, and has the advantage of being made to furnish currents of widely varying electro-motive force. By suitably connecting the machine, as before described, the electro-motive force may be increased to over 120 volts. It possesses, moreover, the advantage of division of the conductor into two circuits, a feature which, however, is also possessed by some forms of other machines. The simplicity and ease of repair of the commutator are also advantages. Again this machine does not heat greatly.

The Wallace-Farmer machine does not return to the effective circuit as large a proportion of power as the other machines, although it uses, in electrical work, a large amount of power in a small space. The cause of its small economy is the expenditure of a large proportion of the power in the production of local action. By remedying this defect, a very admirable machine would be produced. After careful consideration of all the facts, the committee unanimously concluded that the small Brush machine, though somewhat less economical than the Gramme machine, or the large Brush machine, for the general production of light and of electrical currents, was, of the various machines experimented with, the best adapted for the purposes of the Institute, chiefly for the following reasons:—It is adapted to the production of currents of widely varying electro-motive force, and produces a good light. From the mechanical details of its construction, especially at the commutators, it possesses great ease of repair to the parts subject to wear.

In order to make the measurements as accurate as possible, it was found necessary so to arrange the photometric apparatus that no reflected or diffused light should fall on the photometer, and thus introduce an element of error. The electric lamp was enclosed in a box, open at the back for convenience of access, but closed with a non-reflecting and opaque screen during the experiments. Projecting from a hole in the front of the box was a wooden tube, 6 in. square inside and 8 ft. long, with its inner surface blackened to prevent reflection thus allowing only a small beam of direct light to leave the box. This beam of light passed into a similar wooden tube, placed at a proper distance from the first, and holding in its farther end the standard candle. This tube also held the dark box of a Bunsen photometer, mounted on a slide, so as to be easily adjusted at the proper distance between the two sources of light. A slit in the side of the tube enabled the observer to see the diaphragm. The outer end of the second tube was also covered with a non-reflecting hood, and the room was of course darkened when photometric measurements were taken. The rigid exclusion of all reflected or diffused light is the only trustworthy method of obtaining true results, and will, no doubt, account in a large measure for the lower candle-power obtained by these experiments than that obtained by many previous experimenters.

The difficulties encountered in the measurement of the light arising from the difference in colour, were at first thought to be considerable, but further practice and experience enabled the observer to overcome them to such an extent that the error arising from this cause is inconsiderable, being greatly less than that due to the fluctuations of the electric arc.

In determining the amount of light produced by each machine, it was run continuously for from four to five hours, and observations made at intervals, care being taken to maintain the speed and other conditions normal. One of the most important conditions necessary to ensure correct results was the relative position of the carbon points. Great care was taken that the axes of the two sticks or pencils of carbon were in the same line, so that the light produced should be projected equally in all directions. Were the axes of the carbon pencils not in the same line a much greater quantity of light would be projected in one direction, and the result of calculation of the light produced, based on the inverse square of the distance from the photometer, would be too great or too small, according as this adjustment was in the one or the other direction.

Experiments were made to determine what effect on the amount of light was produced by so adjusting the carbons that the front edge of the upper one was in line with the centre of the lower one.

Front	2218 candles
Side	578 "
"	578 "
Back	111 "
	3485 ÷ 4 = 871.

The light produced by the same machine, under the same conditions, except the carbons being adjusted in one vertical line, was 525 candles. This would seem to indicate that nearly 66 per cent. more light was produced by this adjustment of the two carbons; but a close study of the conditions proves that such is not the case and that there is no advantage to be derived from such adjustment, except when the light is intended to be used in one direction only.

The following is a statement upon this point, in the report of N. Douglass, Engineer to the Trinity House:—

I have found this arrangement of the carbons, the axis of the bottom carbon nearly in the same vertical plane as the front of the top carbon, and assuming the intensity of the light with the carbons having their axes in the same vertical line to be represented by 100, the intensity of the light in four directions in azimuth, say E., W., N., and S., will be nearly as follows:—

East or front intensity	287 to 100
North or side "	116 " 100
South " "	115 " 100
West or back "	38 " 100
	556 ÷ 4 = 139 to 100.

In measuring the candle-power of the light produced by each machine, I have given the mean intensity obtained in the direction of the photometer, the carbons in lamp working with the Holmes and Alliance machines being always arranged with the axes in the same vertical line, and the carbons in the lamp working the Gramme and Siemens' machine being always arranged with the front edge of the top carbon nearly on the centre of the bottom carbon.

It is, therefore, evident that the results given by Douglass must be divided by 2·87 in making a comparison with those obtained by the Franklin Institute Committee.

The following abstract, Table VIII., from a report of J. Tyndall, addressed to the Trinity Board, upon experiments carried out to ascertain the relative values of different apparatus, completes the list as regards other machines than the preceding.

The machines experimented on were the following:—

Holmes' machines, which have been already established for some years at the South Foreland Lighthouse. Gramme's machine. Two Gramme's machines coupled together. Siemens' large machine. Siemens' medium machine.

TABLE VIII.—COST, DIMENSIONS, WEIGHT, HORSE-POWER ABSORBED, AND LIGHT PRODUCED BY THE DYNAMO-ELECTRIC MACHINES, tried at the South Foreland, 1876-77.

Names of Machines.	Dimensions.			Weights.	Horse power Absorbed.	Revolutions a Min.	Light produced, in Standard Candles.		Light produced each Horse-power in Standard Candles.		Size of Carbons.
	Length.	Breadth.	Height.				Condensed Beam.	Diffused Beam.	Condensed Beam.	Diffused Beam.	
	ft. in.	ft. in.	ft. in.	tons cwt. qr. lb.							
Holmes	4 11	4 4	5 2	2 11 1 7	3·2	400	1,523	1,523	476	476	3/8 by 3/8
Alliance	4 4	4 6	4 10	1 16 1 21	3·6	400	1,953	1,953	543	543	3/8 " 3/8
Gramme, No. 1	2 7	2 7	4 1	1 5 2 0	5·3	420	6,663	4,016	1,257	758	1/2 " 1/2
" " 2	2 7	2 7	4 1	1 5 2 0	5·74	420	6,663	4,016	1,257	758	1/2 " 1/2
Siemens, large..	3 9	2 5	1 2	0 11 2 18	9·8	480	14,818	8,932	1,512	911	11/16 " 11/16
" small—											
No. 58	2 2	2 5	0 10	0 3 3 0	3·5	850	5,539	3,339	1,582	954	1/2 " 1/2
" 68	2 2	2 5	0 10	0 3 3 0	3·3	850	6,864	4,138	2,080	1,254	1/2 " 1/2
2 Holmes	9 10	4 4	5 2	5 2 2 14	6·5	400	2,811	2,811	432	432	1/2 " 1/2
2 Gramme ..	5 2	2 7	4 1	2 11 0 0	10·5	420	11,396	6,869	1,085	654	11/16 " 11/16
2 Siemens, medium	4 4	2 5	0 10	0 7 2 0	6·6	850	14,134	8,520	2,141	1,291	11/16 " 11/16

These last three measures were taken with the machines coupled in multiple arc, the effect being a considerable increase in light produced for power expended.

M. Tresca has made a series of experiments in the establishment of MM. Sautter and Lemonnier, to ascertain the amount of work performed by the Gramme machine for the production of light.

The high speed at which the Gramme machine is driven, rendered it difficult to employ a dynamometer which should not make more than 250 revolutions a minute. The diagrams obtained were, however, satisfactory after some preliminary trials. The work done has thus been accurately determined, but this was not the case with the luminous intensity. This latter was measured direct by a photometer with two discs, one illuminated by a Carcel lamp, and the other by the electric lamp. One of these discs appeared of a green hue in relation to the other, which was rose-tinted, and amongst the various methods tried, it was found decidedly the best to correct the difference of these tints by the interposition of two Carcel lamps, burning 1·48 oz. an hour, and at a suitable distance from the photometer, the electric light being placed at a distance of 131·23 ft. in the first, and 65·61 ft. in the second trial.

In spite of the uniformity of the electric current supplied to the regulator, the light, on account of the irregularity in the nature of the carbons, showed oscillations, which for the most part were perceptible only in the photometric determinations, but on that account a great difficulty arose in determining exactly the intensity and its definition in relation to the expenditure of power.

It was only possible to avoid these drawbacks by increasing the number of trials, and limiting their duration to very short periods. The standard lamp having been placed in such a position as to balance the average intensity of the electric light, the apparatus was kept at work during a certain time, and at the instant that an apparent equality was observed, a signal was given to the experimenter stationed at the dynamometer, and a diagram comprising a period of a few seconds was obtained. Another observer recorded the speed of the dynamometer each minute, and the dynamometer diagram was renewed only at a fresh signal from the operator at the photometer. Tables IX. and X. give all the data obtained from the successful experiments thus conducted.

TABLE IX.—EXPERIMENTS WITH LARGE GRAMME MACHINE.

Ratio of distances of electric light and Carcel lamp from photometer .. .. 40 : 93
Ratio of intensities .. .. 40 : 93 = 1850

Numbers of Diagram.	Revolutions of Dynamometer a Minute.	Mean Ordinates given by the Diagrams.	Foot-pounds of Work a Second.
		in.	
1	238	·885	4883
2	251	·744	4324
3	248	·854	4916
4	244	·653	3693
5	241	·614	3226
6	244	·654	3716
Mean	244	..	4127 = 7·5 { H.-P. a minute.

Work done for 100 burners .. .. .. 7·5 : 1850 = 405 horse-power.
Work each burner a second .. .. .. 2·23 foot-pounds.

TABLE X.—EXPERIMENTS WITH SMALL GRAMME MACHINE.

Ratio of distances of electric light and Carcel lamp from photometer 20 : 1·15

Ratio of intensities .. .. 20 : 1·15 = 302·4

Number of Diagram.	Revolutions of Dynamometer a Minute.	Mean Ordinates of Diagram.	Work done in Foot-pounds a Second.
		in.	
1	234	·279	1452
2	238	·262	1445
3	244	·292	1651
Mean	239	..	1516=2·75 { H.-P. a minute.

Work done for 100 burners .. .. 2·75 : 302·91 horse-power.
Work each burner a second .. .. 4 : 97 foot-pounds.

In order to ascertain the number of revolutions of the main shaft of the magneto-electric machine, it was necessary to make certain that there was no slipping of the driving belt. By various experiments, the speed of the two shafts was tested by means of two counters, and it was thus found, in the first trial, that the actual ratio of the speed was 5·18, the ratio calculated from the diameters of the pulleys, and the thickness of belts being 5·26. The speed of the Gramme machine shaft was thus found by multiplying the mean speed of the dynamometer shaft by 5·22, which gave for the first series of trials, 1264 turns a minute; in the second series, the ratio of speeds being only 3·65, and the mean speed of the dynamometer 239 turns a minute, the number of revolutions of the machine was 239 × 3·65 = 872. The apparatus, which gave a light of 1850 Carcel lamps, is arranged as follows;—The horizontal shaft carries two series of conductors placed symmetrically, the one on the left receiving the current from 15 bobbins spaced around a soft-iron ring. In the intervals between these are 15 other bobbins in connection with the conductor placed on the other side of the shaft. The two currents combine when the bobbins turn around the shaft in front of the poles of the four electro-magnets, put in operation by a portion of the current, the balance being led off to the electric lamp. The following are the leading dimensions of the machine:—

Electro-magnets:—

Diameter of the electro-magnet	2·75 in.
Length	15·90 "
Diameter of coil	5·19 "
" wire	·125 "

Weight of copper rolled around each electro-magnet	52·8 lb.
Bobbins :—	
Outside diameter of soft-iron ring	7·67 in.
Inside " "	6·18 "
Width of soft-iron ring	4·68 "
Outer diameter of bobbin	9·05 "
Inner " "	4·72 "
Diameter of wire	·1 "
Total weight of wire	308 lb.
Diameter of conducting cylinders	3·54 in.
" lamp wire	·3 "
Machine :—	
Total length, including pulley	31·5 "
" height " "	23·03 "
" width " "	21·65 "

The machine giving a light of 3000 Carcel lamps is more simple, as it has only a single series of conductors and small bobbins, and two electro-magnets only. The following are its leading dimensions :—

Electro magnets :—	
Diameter	2·75 in.
Length	13·97 "
Diameter of coil	4·72 "
" wire	0·15 "
Weight of copper around electro-magnet	31·5 lb.
Bobbins :—	
Outside diameter of soft-iron ring	6·61 in.
Inside " "	4·84 "
Width of soft-iron ring	3·97 "
Outside diameter of bobbin	4·68 "
Inside " "	4·05 "
Diameter of wire	·07 "
" conducting cylinder	3·5 "
" wire to lamp	·34 "
Machine :—	
Total length, including pulley	25·6 "
" height " "	19·92 "
" width " "	16·14 '

The large machine supplies a lamp made at the works of M. Gramme, with carbons of ·123 sq. in. in section; the lamp for the smaller machine was made by M. Serrin, with carbons of similar dimensions.

The machines worked with regularity for a sufficient time to prove the absence of heating. Moreover, the work done was very uniform during the experiments, although one of them was considerably prolonged.

As regards the cost of different modes of lighting, the following data are of interest. The consumption of oil for 1850 Carcel burners an hour equals 1850 × 1·48 oz. = 2738 oz., or about 6800 cub. ft. of gas. Under these conditions the cost of fuel would be only the hundredth part of cost in oil, and one-fiftieth part of the cost of gas-lighting in Paris. The comparison is less favourable for smaller machines, for from the data given it will be seen that for the large machine, each Carcel burner requires 2·23 foot-pounds, and for the small machine, 4·97 foot-pounds, or double the former. This expenditure of work would, according to M. Heilmann, be increased to 1·85 foot-pounds for each burner in a hundred-light machine.

A lamp of 100 burners, to light a workman as well as would an ordinary lamp placed 18 in. away from him, may be situated 16·5 feet away; a lamp of 300 burners may be 28·5 ft., and one of 1850 burners at 70 ft. 4 in.; these figures show that the largest sizes of lamps may be most usefully employed for lighting manufactories.

During the competitive trials at the Franklin Institute, as to the relative efficiency of the machines as noted in the preceding pages, Professors Houston and Thomson took the opportunity thus afforded to make a careful study of many interesting circumstances which influence the efficiency of these machines.

A convenient arrangement of the particular circumstances to be discussed is, those affecting the internal work of the machines; those affecting the external work; and the relations between the internal and external work.

The mechanical energy employed to give motion to a dynamo-electric machine is expended in two ways; in overcoming the friction and the resistance of the air; and in moving the armature of the machine through the magnetic field, the latter, of course, constituting solely the energy available for producing electrical current.

The greatest amount of power expended in the first way was noticed to be about 17 per cent. of the total power employed. This expenditure was clearly traceable to the high speed required by the machine. The speed, therefore, required to properly operate a machine is an important factor in ascertaining its efficiency. The above percentage of loss may not appear great; but when it is compared with the total work done in the arc as heat, constituting, as it did in this particular instance, over 50 per cent. of the latter, and about 33 per cent. of the total work of the circuit, its influence is not to be disregarded. In another instance the work consumed as friction was equal to about 80 per cent. of that appearing in the arc as heat, while, in the Gramme machine experimented with, this percentage fell to 20 per cent. of that which appeared in the arc as heat, and was only 7 per cent of the total power consumed in driving the machine.

In regard to the second way in which mechanical energy is consumed in overcoming the resistance necessary to move the armature through the magnetic field, or, in other words, to produce electrical current, it must not be supposed that all this electrical work appears in the circuit of the machine, since a considerable portion is expended in producing local circuits in the conducting masses of metal, other than the wire, composing the machine.

The following instances of the relation between the actual work of the circuit, and that expended in local action, will show that this latter is in no wise to be neglected. In one instance an amount of power somewhat more than double the total work of the circuit was thus expended. In this instance also it constituted more than five times the total amount of power utilized in the arc for the production of light. In another instance it constituted less than one-third the total work of the circuit, and somewhat more than one-half the work in the arc.

Of course, work expended in local action is simply thrown away, since it adds only to the heating of the machine. And, since the latter increases its electrical resistance, it is doubly injurious.

The local action of dynamo-electric machines is analogous to the local action of a battery, and is equally injurious in its effects upon the available current.

Again, in regard to the internal work of a machine, since all this is eventually reduced to heat in the machine, the temperature during running must continually rise until the loss by radiation and convection into the surrounding air equals the production, and thus the machine will acquire a constant temperature.

This temperature, however, will differ in different machines, according to their construction, and to the power expended in producing the internal work, being, of course, higher when the power expended in producing the internal work is proportionally high.

If, therefore, a machine during running acquires a high temperature when a proper external resistance is employed, its efficiency will be low. But it should not be supposed that because a machine, when run without external resistance, that is, on short circuit, heats rapidly, that inefficiency is shown thereby. On the contrary, should a machine remain comparatively cool when a proper external resistance is employed, and heat greatly when on short circuit, these conditions should be regarded as a proof of its efficiency.

In regard to the second division, the external work of the machine, this may be applied in the production of light, heat, electrolysis, magnetism, and the like.

Where it is desired to produce light, the external resistance is generally that of an arc formed between two carbon electrodes. The resistance of the arc is therefore an important factor in determining the efficiency, To realize the greatest economy, the resistance of the arc should be low, but nevertheless should constitute the greater part of the entire circuit resistance.

In some measurements the resistance of the arc was surprisingly low, being in one instance 0·54 ohm, and in another 0·79 ohm. It was, however, in some instances as high as 3·18 ohm. The amount of work appearing in the arc, as measured by the number of foot-pounds equivalent, is not necessarily an index of the lighting power.

Perhaps the highest estimate that can be given of the efficiency of dynamo-electric machines, as ordinarily used, is not over 50 per cent.; measurements have not given more than 38 per cent. Future improvements may increase this proportion. Since the efficiency of an ordinary steam-engine and boiler, in utilizing the heat of the fuel, is probably over-estimated at 20 per cent., the apparent maximum percentage of heat that could be recovered from the current developed in a dynamo-electric machine, would be over-estimated at 10 per cent. The economical heating of buildings by means of electricity may therefore be regarded as totally impracticable.

In respect to the relations that should exist between the external and the internal work of dynamo-electric machines, it will be found that the greatest efficiency will, of course, exist where the external work is much greater than the internal work, and this will be proportionally greater as the external resistance is greater. Measurements gave, in one instance, the relation of ·82 ohm of the arc to ·49 ohm of the machine, a condition which indicates economy in working. The other extreme was found in an instance where the resistance of the arc was 1·93 ohm, while that of the machine was 4·60 ohms, a condition indicating wastefulness of power.

TELEPHONES.

Probably the earliest instrument devised for transmitting sound by the agency of electricity was the musical telephone invented by P. Reis, in 1860, who afterwards introduced the improved form, Fig. 1. The instrument is in two parts, a transmitter A, and a receiving instrument R. The transmitter has a membrane S, stretched over a circular hole at the top of a cubical box A, in front of which, and opening into it, is a mouthpiece M. The membrane vibrating in unison with the impulses it receives from musical sounds played near it, transforms those impulses into a series of electrical currents, by a simple make-and-break arrangement *g*, and these currents acting on the receiving instrument, which may be hundreds of miles distant, reproduce the corresponding notes, so that a tune played at one station can be distinctly heard at the other.

Fig. 1.

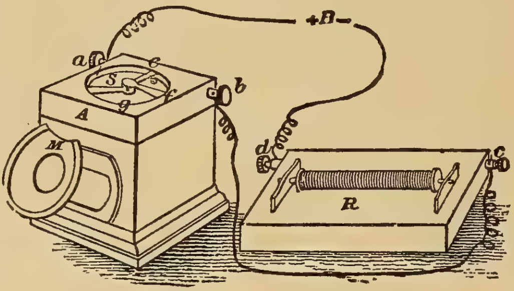
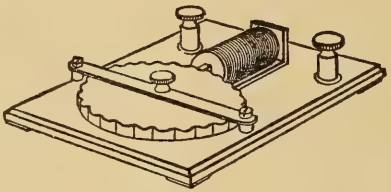


Fig. 2.



Reis's receiving instrument is founded upon the phenomenon discovered by Page in 1837, that a distinct sound accompanies the demagnetization of an iron bar, placed in an electro-magnetic helix. It consists of a soft iron bar about the size of a knitting needle, surrounded by a helix of wire, which forms part of a voltaic circuit, including the battery B, with the transmitting instrument; and, for intensifying the effect, both instruments are provided with sounding-boards.

When notes are sounded into the mouthpiece, the membrane is thrown into vibration, and a platinum plate, attached to its centre, makes and breaks contact with a contact screw, and in so doing completes and interrupts an electric current which traverses the receiving instrument, the bar of which becomes magnetized and demagnetized at each complete vibration. By this means, the note sounded into the transmitter is reproduced by the receiver, the action of the two instruments being isochronous.

Varley devised a musical telephone, using a tuning-fork, in conjunction with an electrical condenser, to transmit vibratory currents to a distant station, and there to reproduce musical sounds.

P. Lacour has constructed a remarkable instrument, termed a phonic wheel, which is susceptible of many important applications. This wheel, which is in reality a small electro-magnetic machine, is so arranged that, when set in motion by electric vibrations produced by the action of an electric-diapason or telephone, it obtains a perfectly uniform rotary movement, which is not interfered with by external mechanical reaction not sufficiently powerful to arrest it.

Fig. 2 of the phonic wheel, consisting of a toothed wheel of soft iron, movable about its axis, facing which is placed a straight electro-magnet, so that one of its poles, when excited, reacts upon the teeth without contact, similar to the action of electro-magnetic machines having a direct movement of rotation. If a series of currents having equal duration and intervals, as transmitted by an electro-diapason, be sent through the electro-magnet, the reaction of the latter upon the teeth results in a series of attractive effects, which can maintain an initial movement communicated to the wheel, and rendering this perfectly uniform, when the rapidity of rotation is such that the wheel traverses in each period occupied by a current, a space equal to the distance between the consecutive teeth. Currents thus transmitted are distributed by an electro-diapason or telephone,

Fig. 3.

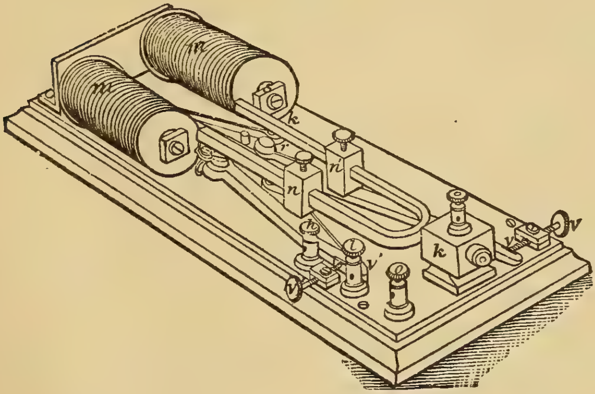


Fig. 3, which consists of a tuning-fork placed horizontally, with its stem projecting through a wooden stand *k*.

The position obtained at each movement by this wheel, is such a function of the times as can be designated as mobile equilibrium. The reality of its existence can be proved by slightly urging or retarding the wheel in its motion. If the movement be opposed, the attraction will accelerate it more than retard it. If the velocity of the wheel be augmented, the retarding action will be greater than the accelerating action. Thus a slight deviation communicated to the wheel in either direction is compensated and rendered valueless, by reason of the compensating attractions; and the mobile equilibrium constitutes therefore a condition of stable equilibrium.

Lacour states, if an electro-magnetic diapason is caused to react upon a current traversing the electro-magnet of a phonic wheel, this wheel, when once it has obtained a movement which causes one tooth of the wheel to pass in front of the electro-magnetic pole during each electric wave, will preserve a position of uniform movement, which can be termed a regulated movement, analogous to that of repose of the wheel when one particular tooth is attracted in the direction of the pole.

If the phonic wheel be travelling with a regulated motion, and an external force tends to slightly deviate it from the position of mobile equilibrium, the phono-electric current causes it to return to this position. But if this force remains constant, the wheel, still preserving its velocity of rotation, will find another position of mobile equilibrium, which will depend upon the force and its direction in reference to that of the rotation. It is this constancy in the velocity of the phonic wheel, despite external forces, that permits of its application to chronographs and to apparatus in which a synchronous motion is necessary. These forces must not, of course, exceed a certain limit. If the external force exceed the limiting value, the mobile equilibrium is destroyed, and the velocity of the wheel accelerated or retarded according to the direction of this external force. The maximum mechanical force measured is 1 kilogrammetre, = 7·23 foot-pounds, a minute.

There are other velocities at which the phonic wheel may be, and may maintain itself in a position of mobile equilibrium. If the wheel turns with a velocity only half that which corresponds with the regulated movement, so that one tooth passes the pole for every two waves of the phono electric current, the relation of each tooth to one of the two waves of the phono-electric current, will be exactly the same as that when the wheel is regarded as in regulated movement, and this wave maintains the stability of the mobile equilibrium, which might be maintained by the other wave, if the magnetic pole and the teeth of the wheel presented a sharp angle.

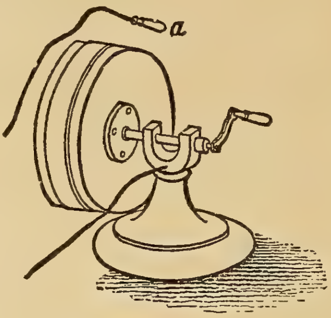
The phonic wheel can maintain itself in rotation with velocities which are the nearest sub-multiples, or multiples, of the velocity of the regulated movement of rotation. At all velocities the phonic wheel turns equally well in either direction.

The phonic wheel is susceptible of a uniform velocity only between certain limits, by reason of the frictions and external actions to which it is subject. The limit depends upon the construction of the wheel, and its extent is small, if any electrical conductors capable of influencing the wheel by induction are in its locality. Lacour has experimented with some phonic wheels, which work only with a velocity determined by 100 waves a second, while others work only under the influence of a phono-electric current giving 600 waves, in the same space of time.

One of the most original of musical telephones is that invented by Elisha Gray. It is founded on a phenomenon first observed by Gray, that when a dry, thin, metallic surface, connected to one end of the secondary current of an induction coil, is rubbed by the hand, while the operator is holding the other end of the secondary wire, a sound is emitted by the hand at the point of contact with the metal, which sound has the same pitch and quality as that given out by the contact-breaker of the coil. Raising or lowering the speed of vibration of this contact-breaker, immediately raises or lowers the pitch of the note. From this Gray was led to construct a key-board containing an octave of keys, each of which on being depressed started into vibration a reed, which, while giving out the note corresponding to its key, transmitted to the induction coil at the receiving end an intermittent current of electricity. With this transmitting instrument the finger of an assistant at the other end, was caused to reproduce whatever tunes were played on the keyboard.

Fig. 4 is of Gray's receiving telephone; in using this instrument the thin metal chamber is connected through the stand to one terminal of an induction coil, in circuit with the musical sound transmitted at the distant station, and the operator, taking hold of a wire *a* connected to the other terminal, presses his fingers on the metal surface while he turns the handle with the other hand. With this simple apparatus every tune played at the transmitting end is reproduced, and the more rapid the rotation, the louder the sound, no sound whatever being emitted when the rotation is suspended.

Fig. 4.



Graham Bell's articulating telephone was introduced in 1876, and is largely in use. In its early stage the transmitting instrument consisted of a horizontal electro-magnet, in front of which and perpendicular to the plane of its axis is fixed a brass ring; over this a membrane is stretched, tightened by means of screws; to the centre of this membrane is attached a small oblong piece of iron, situated immediately in front of, and almost in contact with, the poles of the electro-magnet; binding screws on the stand of the instrument are used to place the coils in circuit with the receiving instrument. This was formed of a thick tube of soft iron, enclosing a vertical bar electro-magnet, rather shorter in length than itself, the two being so connected at the lower end that, while the central bar under the influence of the current assumed north magnetic polarity, the tube surrounding it became by induction a south pole of annular form. To the top of this tube was fastened, by a small screw, an iron disc about the thickness of cartridge paper, and this disc, under the influence of a voltaic current, was held firmly down by the annular pole, its centre being in front of the shorter central pole. It thus constitutes a diaphragm held by its edge by magnetic attraction, its centre being presented to the north pole of a magnet as in the later receiver. The action of the instrument may be explained as follows: When sound waves are projected against the membrane of the transmitting instrument, the iron strip attached to it is set in motion in the manner described, and plays to and fro in front of the poles of the electro-magnet, in obedience to the impulses of the sonorous vibrations; by this action a series of variations in the strength of the currents are induced, proportioned to and synchronous with the variations in the movement of the membranes, and these variations are transmitted by the connecting wire to the receiving instrument, and are reproduced there and converted into sonorous vibrations by means of the diaphragm armature of the receiving instrument.

Fig. 5.

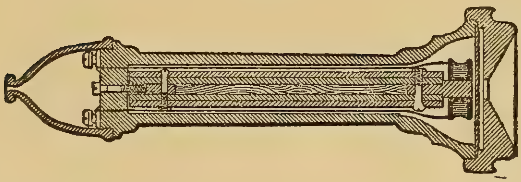


Fig. 5 is a section of a recent form of this instrument, in which several improvements have been introduced. The most important of these is the compound nature of the magnet, which is composed of four bars of steel of flat rectangular section placed in two pairs, which are separated by a similar bar of soft wood, and united at their upper extremity to a soft iron pole-piece, which is surrounded by the coil of insulated wire in circuit with the distant station. The case is constructed of ebonite, and the mouthpiece screws down over the body of the instrument, so as firmly to hold the edge of the ferrotype diaphragm between itself and the rest of the case.

In the Gower telephone, Figs. 6, 7, 8 and 9, the magnet *o* describes a segment of a circle, the narrow, oblong pole N S, which are brought close together in the middle of the chord, being wound with flat coils of fine wire, each having a resistance of 60 ohms. The magnet is composed of French steel, magnetized by a process that enables it to support ten times its own weight. The coils approximate very closely, and the flat coils exert magnetic effect upon the diaphragm. The diaphragm consists of a soft iron plate 3¾ in. in diameter. A brass ring holds it down upon the ledge of the box, which supports it.

Fig. 6.

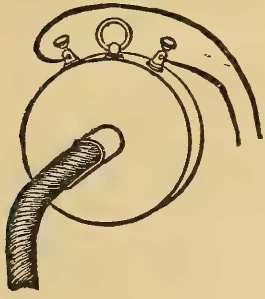


Fig. 7.

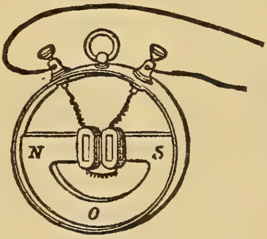
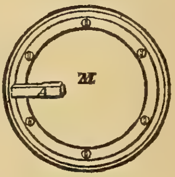


Fig. 8.



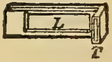


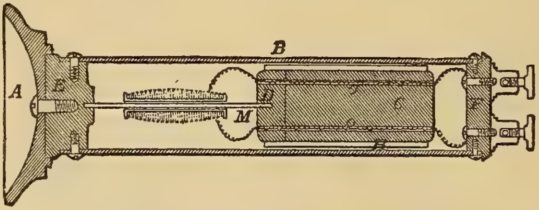
Fig. 9.

The box is of brass, on account of the greater resonance of metal compared to that of wood, and its uniformity of expansion and contraction. Fig. 6 is of the back of the cover of the box, having a flexible speaking tube communicating with the diaphragm, and binding screws for the connecting wires.

The call of the Gower telephone consists of a harmonium or concertina reed, Figs. 8 and 9, fixed to the under side of the diaphragm M, opposite a narrow slit in the latter. Air sent through the speaking tube passes through this aperture in the diaphragm, and agitates the reed, which sounds like a miniature trumpet or horn, and being placed within the magnetic field transmits its note over the telephone wire to the distant station, where it can be distinctly heard. Fig. 8 shows the position the call occupies in the instrument.

Fig. 10 is of the Ader telephone. An iron wire, or strongly magnetized needle M is soldered at each end to a mass of copper E and D, and surrounded by a bobbin or coil of insulated wire. The copper mass D is soldered to a larger mass of lead C, which is perforated longitudinally at O O, to allow the ends of the coil to be brought to the binding screws at F, by which the telephone is connected in circuit. The metal mass D C must be phonetically insulated from the mass E, to prevent confusion of vibrations, consequently D C is encased in a sheet of india rubber H. The ear-piece A is fitted to the instrument, and on listening, while the vibratory currents flow in the coil, the sounds are audible.

Fig. 10.



The general form of T. A. Edison's first telephone somewhat resembles the hand telephone of Bell, although all analogy ends at this point. Through the middle of the body of the case passes a stem, terminating at its upper extremity in a shallow cylindrical box or cup; this stem can be raised or lowered by means of the adjusting screw at the lower end of the case; the cup referred to contains a thin platinum disc, and superimposed upon it a button of carbon, with a second disc of platinum. This series is held in place by an annular cover screwed down on the box, and a thin diaphragm is employed, being held in place by the mouthpiece, which is screwed down upon it, a small piece of rubber-tube being introduced between the diaphragm and the upper platinum disc, in such a manner as to exert a constant, but light, pressure upon the latter. The upper and lower discs of platinum are connected respectively to the two terminal screws, by which the instrument is placed in circuit with the battery and receiving instrument at the other end of the line. The action of this instrument depends upon the varying resistance of the carbon disc, due to variations of pressure exerted upon it by the movement of the diaphragm, under the influence of sonorous vibrations impinging upon it.

The latest form of Edison's carbon transmitter, Fig. 13, has a carbon disc contained within an ebonite ring, screwed to the metallic portion of the frame forming one of the connections of the circuit, and the carbon button A rests upon this metallic surface. The other face of the button is covered with a disc of platinum foil, connected to an insulated terminal, and forming the other circuit connection; this foil is cemented to a disc of glass, in the centre of which is placed an aluminium stud, that bears against the diaphragm D of the instrument. This is an exceedingly simple and compact form of telephone.

Fig. 11. Fig. 12.

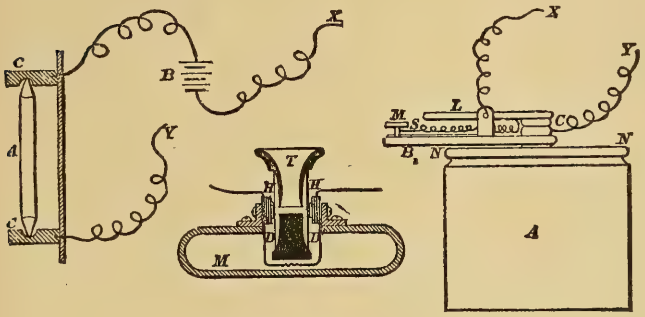
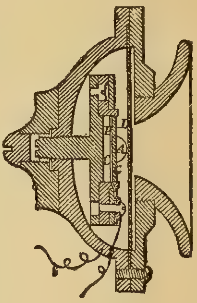


Fig. 14.

Fig. 13.



A novel form of Edison's telephone, Fig. 15, includes a transmitting telephone, a call bell, and a receiving diaphragm. The connecting wires L show the connections between the transmitter and the binding screws to the battery.

F F is a cast-iron standard, into which one end of the spring S is fixed. The pressure of this spring is regulated by the screw B. The main axle is supported by the boss in F F, and is connected to the handle H, by the train of wheels W W′. This handle can be rotated by hand or automatically. Upon the main axle is placed a chemically prepared cylinder of chalk K. The cylinder is a composition of chalk and potassium hydrate, with a small quantity of acetate of mercury, moulded round a brass reel, lined with platinum on the parts in contact with the mixture, which is kept moistened.

A metallic strip is arranged upon, and at right angles to the cylinder, fastened to the diaphragm at D. The pressure of the metallic strip is regulated by the screw S. The diaphragm, Fig. 15, consists of a mica plate 4 in. in diameter. A damping roller M rests in a trough of water and is arranged to be raised against the chalk cylinder when necessary.

Fig. 15.

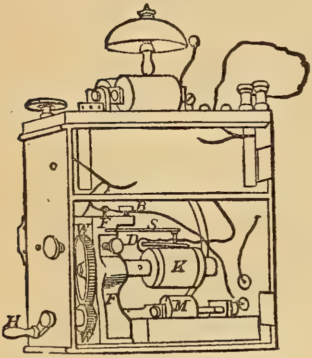
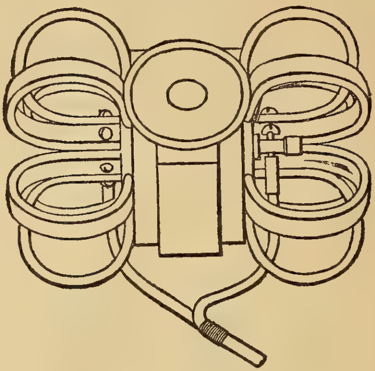


Fig. 16.

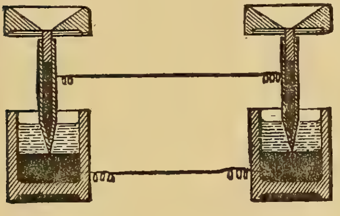


The action of this apparatus is as follows:—Between the metallic strip resting on the chalk cylinder and the chalk, there is a certain amount of friction, and if the cylinder be caused to rotate away from the diaphragm, this friction tends to draw the diaphragm towards the cylinder. The amount of movement given to the mica plate, depends upon the friction between the cylinder and metal, and the friction rises and falls with the quantity of current passing, the greater the current the less the friction, and conversely. By this means the fluctuations of the current produced in the carbon transmitter are faithfully reproduced as sound in the telephone.

The crown telephone, devised by G. M. Phelps, has been used with excellent results in combination with the Edison carbon transmitter. It consists of an ordinary combination of diaphragm, bar magnet and coil, but, in addition, there is a group of six permanent magnets, bent into a circular form, and having their similar poles joined up the central bar carrying the coil. The other ends of these magnets are attached to the edge of the diaphragm. The double crown instrument, Fig. 16, is a duplication of the radial group of magnets described, a pair of coils also being introduced. These coils are so connected that the currents generated by the vibrations of the discs are mutually strengthened.

Another form of the Phelps telephone, Fig. 14, includes a permanent bar magnet, bent so that the poles are brought near to each other. Attached to brackets on the poles of this magnet are two coils, opposite which are two diaphragms H, and between them is the central mouthpiece T opening into a chamber M, in which the pulsations of the air in talking, act upon the diaphragm through lateral openings. The coils are connected together, so that the currents generated by the vibrations of the diaphragm are in the same direction when united, and are consequently much stronger than when only one coil is employed. A similar instrument receives the message at the other end of the line. There is another form of Phelps' instrument, which consists of a mouthpiece placed at the upper part of an oval ebonite case, containing a bent magnet connected to the bar carrying the coil behind the diaphragm, the other pole being attached to the periphery of the diaphragm, in the same manner as are the bar magnets in the crown telephone.

Fig. 17.



In Breguet's telephone, Fig. 17, the transmitter and receiver are alike, and consist of a glass vessel containing mercury, over which floats some acidulated water. The pointed glass tube dipping into the vessel also contains mercury. These two vessels are connected, and over the top of each tube is a mouthpiece and diaphragm. On speaking above the tube of the transmitter, the vibrations are transmitted through the mercury, and contact is made with the acidulated water by means of the small opening left in the tube. The vibratory movements of the mercury by this means generate electro-capillary currents, which flow through to the receiving instrument, and reproduce the conditions which generate them, thus giving out the sounds spoken at the other end.

The sounds that are heard in the telephone are produced by the vibration of the metallic plate or diaphragm, which is set in motion by the variation of magnetic intensity in the permanent magnet placed behind it, which variation of magnetic intensity is produced by a current of electricity traversing the coils, this itself constantly varying in intensity according to the motion of the diaphragm at the distant station. It is not the current alone that produces these results, but the undulatory or constantly varying nature of that current. If at the distant station a single cell of a voltaic battery be substituted for the telephone, there will be heard in the receiving instrument a loud tick whenever the circuit is either made or broken, and if this be repeated with high and uniform velocity, as would be effected by using a tuning-fork as a contact-breaker, a musical note will be heard in the telephone.

If instead of breaking and making contact between a battery and a telephone, the resistance of the circuit or of the battery be suddenly changed, a sound is produced in the telephone more prolonged and more variable. It is this variation of resistance, producing a variation of the current, that led to the invention of the microphone by Hughes, Fig. 11.

It consists of a small pencil of gas carbon A, such as is used in the electric lamp, pointed at each end, and lightly supported in a vertical position between two little cups, scooped out of the surface of small carbon blocks C C, which are attached to a thin sounding-board secured to a more solid base board. The blocks C C are connected by the wires X and Y, to the battery and line-wire leading to the telephone. This simple apparatus, rough as it is, is a most delicate instrument. Not only is articulate speech taken up by it, and transmitted by it to a distant station with great power and distinctness, but it detects and converts into loud noises the minutest possible vibrations. The slightest stroke or the lightest touch, given to the base board, is sufficient to produce a loud grating noise in the telephone.

Another of Hughes's telephones is that illustrated Fig. 12, is an elevation of the instrument. A is a small hollow cylinder of tin plate, closed at one end by the membrane N N of parchment, stretched over it like the head of a drum. To the centre of the membrane is attached a small block of pine, which carries the slip B, also of the same material, the block being of sufficient thickness to cause the farther end of the slip to be clear of the edge of the drum, so that the whole of the rest of the apparatus is supported solely by the centre of the membrane. Upon the slip of pine is fastened one of Hughes's articulating microphones, having a lever of brass L, pivoted at its centre of gravity between two supports, and carrying at one end a small slab of prepared pine charcoal C, which is maintained by the spiral spring S, at a constant pressure against a similar slab of charcoal below it, the latter being attached to the slip of pine. The degree of pressure between the slabs of charcoal may be regulated by turning the milled head M, whereby the tension of the spring may be varied, by winding up or easing of a silk thread attaching to one end of the spring. To the lever L and upper slab C is attached the wire X, and to the lower carbon is connected the wire Y, by which the instrument is placed in circuit with the transmitting apparatus.

Its principle of action is that the carbon blocks at C, Fig. 12, are, under the influence of an undulatory electric current flowing through them, thrown into a state of mechanical vibration, and this vibration is rendered audible by a series of little blows upon the membrane to which the apparatus is attached, and the sound so increased is again still further reinforced by the resonating cavity over which the membrane is stretched.

Hughes's sonometer or audiometer is intended for conducting aural investigation with absolute accuracy, a line of inquiry hitherto limited, for the want of such an instrument. It is represented by the accompanying Fig. 18, and consists of a small bed-plate with a bracket at each end to carry a horizontal rod 200 millimetres in length, and of the section shown. At one end of this rod is fixed a bobbin *a*, with 100 metres of insulated wire wound upon it, and at the other is a similar but smaller bobbin *c*, upon which is wound

Fig. 18.

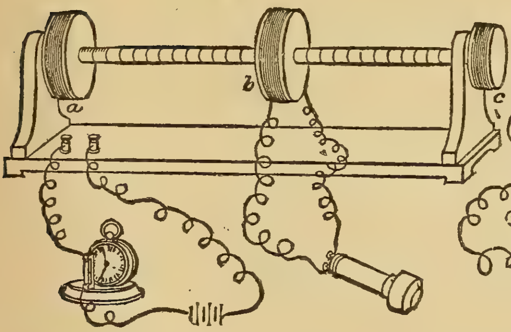
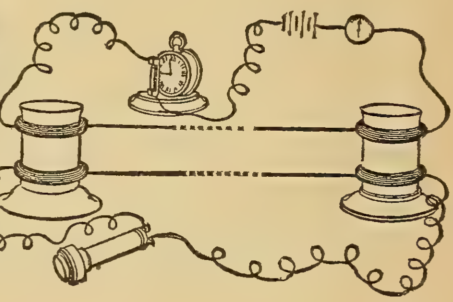


Fig. 19.



about 1 metre of insulated wire. These coils are so connected together as to have opposite, but necessarily inductive, influences upon *b*. They are placed in circuit, with a battery, a galvanometer, and a clock-microphone. Sliding on the rod is the third bobbin *b*, carrying 100 metres of wire, in every respect similar to the bobbin *a*, and having a telephone in circuit with it. Induction will make the clock audible by means of the telephone, but with varying loudness, according to its relative distances from the bobbins *a* and *c*; but there exists a point on the rod where the induction from *c* is equal to, and entirely neutralizes that from *a*, and absolute silence then ensues. This zero point is nearer to *c* than *a*, on account of the difference in the power of the coils, for if both were equal the zero point would be equidistant between them. The only object in making *a* and *c* of different proportions is to ensure a longer range or scale. The rod is divided into centimetres or any other convenient units. To test the aural power of any person, it is only necessary to place the telephone coil against the bobbin *a*, and slide it slowly towards zero, until the point is reached when the ticking of the clock becomes inaudible; the scale on the rod then indicates exactly the aural power, which can be thus denominated by a number, the value of which may be fixed to any convenient standard.

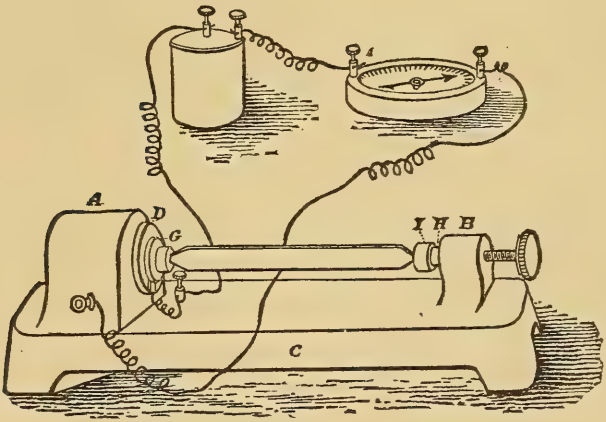
A second application of Hughes's balance is represented by Fig. 19. In this a different principle is employed, for whereas in the audiometer one coil is shifted to and fro until perfect equilibrium is attained, in this one a perfect electrical balance is permanently established, and upon its accuracy the delicacy of the instrument depends. It consists of two hollow cylindrical boxes, around each of which are wound two parallel coils. One pair of these is connected by a line, and is placed in circuit with a battery and clock-microphone. The other pair is also connected with a wire, and joined in a telephone circuit. The induction set up in the secondary line, from the current passing through the primary coils, is balanced by the reversal of one of the bottom coils, and adjusted to an absolute silence point. The distance between the two boxes is immaterial. If any metallic substance, a coin for example, be placed in one of the boxes, the balance is destroyed, by the resistance set up in the body of the metallic substance introduced, and the ticking becomes audible, and so delicate can the adjustment be made, that if two coins, similar, but not absolutely identical in weight or composition, be introduced, the difference can be at once detected by the sound. In this way the existence of impurities in metals, or of inequalities in alloys, too minute to be discovered by analysis, are instantly detected, while perfect similarity is also as instantly proved.

A result of T. A. Edison's experiments with his carbon telephone transmitter, is the construction of an instrument for detecting minute changes of temperature, which greatly surpasses the thermopile in delicacy.

In determining the thickness of carbon buttons best suited to the transmission of articulate sounds, Edison discovered that within certain limits increased thickness gave increased sensitiveness; but after using the instrument a short time it became inarticulate, and finally inoperative. Investigation proved this to be the result of expansion of the hard rubber handle by the heat of the hand. This difficulty was overcome by a different method of attaching the carbon button, suggesting at the same time a new use for its extreme sensitiveness.

The micro-tasimeter, Fig. 20, consists of a rigid iron frame for holding the carbon button, which is placed between two platinum surfaces, one of which is fixed and the other movable, and a device for holding the object to be tested, so that the pressure resulting from the expansion of the object acts upon the carbon button.

Fig. 20.



Two posts, A B, project from the rigid base-piece C. A vulcanite disc D is secured to the post A by a platinum-headed screw, the head of which rests in the bottom of a shallow circular cavity in the centre of the disc. In this cavity, and in contact with the head of the screw, the carbon button is placed. Upon the outer face of the button there is a disc of platinum foil, which is in electrical communication with the battery. A metallic cup G is placed in contact with the platinum disc.

The post B is about 4 in. from the post A, and contains a screw follower H, that carries a cup I, between which and the cup G is placed a strip of any substance whose expansibility it is desired to exhibit. The post A is in electrical communication with a galvanometer, and the latter is connected with the battery. The strip of the substance to be tested is put under a small initial pressure, which deflects the galvanometer needle a few degrees from the neutral point. When the needle comes to rest, its position is noted. The slightest subsequent expansion or contraction of the strip will be indicated by the movement of the galvanometer needle. A thin strip of hard rubber placed in the instrument exhibits extreme sensitiveness, being expanded by heat from the hand, so as to move the needle of a very ordinary galvanometer through several degrees, which is not affected in the slightest manner by a thermopile facing and near a red-hot iron. The hand, in this experiment, is held a few inches from the rubber strip. A strip of mica is sensibly affected by the heat of the hand, and a strip of gelatine placed in the instrument is instantly expanded by the moisture from a damp piece of paper held 2 or 3 inches away.

The instrument is arranged for these experiments in single circuit, but for more delicate operations it is connected with a Thomson's reflecting galvanometer, and the current is regulated by a Wheatstone's bridge and a rheostat, so that the resistance on both sides of the galvanometer is equal, and the light pencil from the reflector falls on 0° of the scale.

The disturbing effect of electrical induction upon telegraph and telephonic lines, was treated at length by D. E. Hughes, in a paper communicated to the Society of Telegraph Engineers in 1879, and he then detailed a series of experiments, which resulted in the introduction of mechanical arrangements for effectually eliminating, from a group of any number of lines, the effects of induction, assuring the protection of each and all, whether one or more lines are being worked at the same time.

Edison's method, Fig. 21, simply has reference to the protection of one wire, such as a circuit against the influence of other circuits, without regard to their influence upon one another.

Edison's arrangement consists in placing one or more electro-magnets, Fig. 21, in the circuit of the telephone, and one or more electro-magnets in the circuit of the adjacent wires, and bringing the opposite cores of the wire magnets at such a distance from the cores of the telephone magnets, that a certain magnetic action will be set up in the latter, by induction in the opposite direction to the induction currents from the adjacent line or lines. By adjusting the distance between these magnets when the telephone is not in use, until there is not any sound at the diaphragm from the induction currents, then those currents will be neutralized, whether strong or weak, and will not produce any false sounds when the telephone is in use.

C. H. Wilson, of Chicago, was one of the first to point out an arrangement by which two telegraph lines may be compensated for induction. Wilson's device, Fig. 22, consists of a bar of soft iron carrying two coils of insulated wire, which are respectively placed in the circuits of the two wires. The effect, therefore, of a current traversing one of the coils would be to induce in the other coil a corresponding magneto-electric current, and the coils are so connected to their respective lines, that the currents induced by the coils, are in a reverse direction to those induced by the lateral induction of the line wires. But as a magneto-electric current so produced would in most cases produce a more powerful effect than that due to lateral induction, Wilson short circuits each of the coils, through a resistance box R and R, and these resistances are so balanced against one another, and adjusted for the relative influences of the coils and lines, that mutual compensation is ensured. Electro-magnets are also introduced into the circuits, to act as con-

Fig. 21.

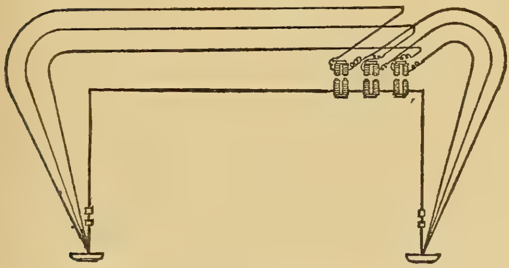
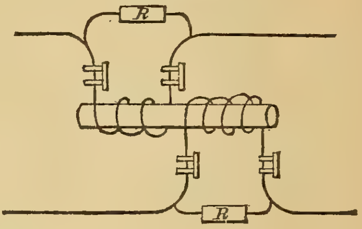


Fig. 22.



densers, for prolonging the duration of the effects produced, so as to make the apparatus equally applicable for long as for short circuits.

ELECTRIC FIRE-ALARMS.

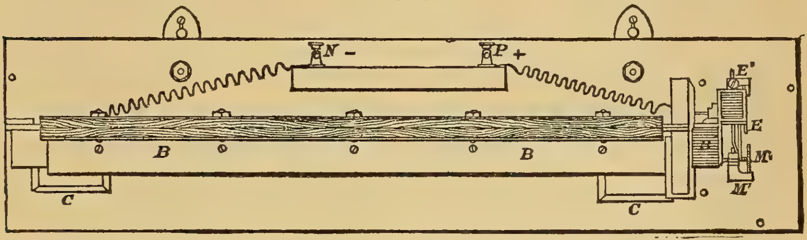
There are many contrivances for automatically announcing the origin of a fire to the inmates of a building or the watchman on duty. A Bain's fire-alarm consists of a column of mercury in a thermometer completing a battery circuit, and sounding an alarm, when the temperature of the locality in which it is placed, rises to a certain degree. This was among the first examples of this species of fire-alarm, and it is one still largely employed in warehouses and in the holds of ships. Many different arrangements have been devised to effect the same purpose, such as inflammable threads and strings passing through apartments, the explosion of bombs, and the dilatation of wires and bars of alloys by increase of temperature, the expansion of air, or some other gas, in a vessel having an elastic wall, and other more or less complex mechanisms. Du Moncel invented an electro-automatic thermometer similar to Bain's, but it was only intended to maintain the temperature of rooms or workshops beneath a certain fixed datum, and not to be a fire tell-tale, although it might have been easily modified for that purpose. It is obvious that such tell-tales with fixed maxima are open to some objection, since, in order to prevent false alarms, it is necessary to know the maximum temperature which the apartment ordinarily acquires, and from the fact that a fire might have broken out, and made considerable headway, in some part of the place, before the fixed maximum temperature was reached on the tell-tale.

All these plans, however, only give the alarm when a certain definite temperature, decided upon beforehand, has been reached. The fire-alarm of Jules Leblanc, of Tourcoing, France, is, therefore, an improvement upon the foregoing methods, inasmuch as it signals all sudden elevations of temperature whatever.

Leblanc's tell-tale will automatically follow or adjust itself to the normal variations of temperature, however high they may be, in the room in which it is placed, and under the influence of a sudden and abnormally rapid rise of temperature will actuate an alarm signal.

It is based upon the property which certain materials, such as felt, thick woollens, and the like, possess, of behaving as good conductors of heat, when the heat varies by insensible degrees, like that emitted by the sun or stoves, but as bad conductors when the variation in question is sudden and accidental. It is, in fact, a kind of differential thermometer, regulated automatically. The part sensitive to heat is constructed of zinc, which is one of the metals whose coefficient of expansion is the highest. Fig. 23 represents

Fig. 23.



an elevation of the apparatus, fixed upon a base of wood little liable to expand and warp under heat; C and C two upright metal supports bolted to the base; between these is a wooden plank on edge, upon which are fastened two expansible plates of sheet zinc, about 60 centimetres long and 0.05 centimetres thick, cut from the same piece so as to expand equally. They are doubled into a gutter shape, to render them more rigid, and are fixed at one end to the support C, while being free to move at the other end through openings in the support. One of these plates, B, is covered with a wrapper of cloth or felt, which retards the effect of sudden changes of temperature on the metal within it; the other plate, on the contrary, is bare, and susceptible to the surrounding changes of temperature. Of exactly the same length and similar quality, these two plates give sensibly the same linear dilatation for each degree. The two zinc plates are arranged one above the other, with some little space between them; only the upper plate is shown in the plan, Fig. 22. B′ is a square box soldered to the extremity of the plate B, and E′ is a small bar fixed to the box B′, but isolated from it, and carrying an adjustable contact screw E. By means of this screw the range of the tell-tale is regulated. The head is milled with 120 teeth, and each tooth represents a quarter of a degree of temperature, so that an interval from a fraction of a degree to several degrees Centigrade, may be at will adjusted, between the contact point of the screw and the spring platinum contact F, attached to the free end of the bare zinc, according to the degree of sensibility required in the apparatus. The bare zinc carries at its extremity a metal piece which has two spring contacts, which are intended to make contact with the screws E and M, when the bare plate expands far enough. M′ is a small insulating bar supported by the base board D, and carrying the second regulating screw M, which is added to the apparatus as a second tell-tale of the old sort, namely, with a fixed maximum, determined beforehand. It has fifty teeth round its head each representing a degree Centigrade. The screws E and M are connected by wire with the terminal P, to which is led one pole of a battery, and the fixed ends of the zinc plates are also connected by wire to the terminal N, to which is led the other pole of the battery. When the bare plate expands sufficiently far to carry the spring into contact with the screw E the battery circuit will be completed, and a local gong in the circuit actuated. There are small spring ratchets gearing in the teeth of the screws E and M, and holding the latter in their adjusted positions. All the contact points are faced with platinum, to avoid oxidation, and the whole is enclosed in a protecting case to exclude the dust. In use the screw E is adjusted so as to leave an interval of one degree between it and the contact spring. So long as the variations of temperature in the room are sluggish, the flannel or felt round the zinc plate B, which carries the screw, will not interfere with the sensitiveness of the plate it covers. The relative distance of the two contacts will therefore be preserved with very little alteration, since the screw is carried by one plate and the spring by the other. But if there is a sudden rise of temperature due to any cause, the bare plate will first feel its effects, and expand so rapidly in relation to the plate swathed in flannel, that the spring contact will be carried forward into connection with the screw contact, the electric circuit will be completed, and the alarm will be sounded.

The case of a sudden rise of temperature is that to be most frequently anticipated; but there might be fires which take their rise slowly and gradually; this would prevent the closing of the circuit in the manner described, and defeat the object of the tell-tale. This contingency is provided for by adding to the differential maximum arrangement an auxiliary contact, which takes place at a fixed maximum temperature. The best side for the tell tale is, usually, near the ceiling of the apartment, in some place where heat tends to accumulate under the action of air currents.

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